LPWA 2018

LPWA Business Models and Forecasts by Vertical Market

LoRa, Sigfox, RPMA, Telensa, LTE-M, NB-IoT, 5G IoT

Abstract:

This report provides specific guidance on which LPWA connectivity will be used in key vertical markets including asset tracking, healthcare, smart meters, smart cities, and Industrial IoT. Business model factors and technical factors that influence the growth of LTE-M, NB-IoT, 5G IoT, LoRa, and other formats are illustrated in detail.

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J.Madden
July 2018

LPWA 2018

FIGURES

CHARTS

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1 EXECUTIVE SUMMARY

Only two years ago, the LPWA market was a chaotic competition between at least 12 different wireless formats. Today, LPWA segmentation is becoming more clear, and the winners and losers are more obvious.

The primary distinction between different LPWA formats is not the technology itself but the business model that is applied. Regardless of RF performance, some enterprises insist on controlling their own networks. This gives LoRa a major boost, along with a few other unlicensed technologies that focus on specific vertical markets. LoRa takes best advantage of the private-network business model because of its open ecosystem and good RF/battery performance. The unlicensed formats with closed ecosystems (e.g. Sigfox and others, where users are forced to use a common network) are less successful in the private networking area.

For applications that benefit from a widespread network, LTE-M and NB-IoT are quickly sweeping up the attention of major customers. Mobile networks have now been upgraded inexpensively (via software upgrades) to instantly create nationwide coverage, where competing unlicensed formats are still slowly building up their coverage.

Overall, we see two major market areas emerging here, with distinct needs for private networks and other requirements for high RF performance and wide coverage. LoRa and NB-IoT are the big winners.

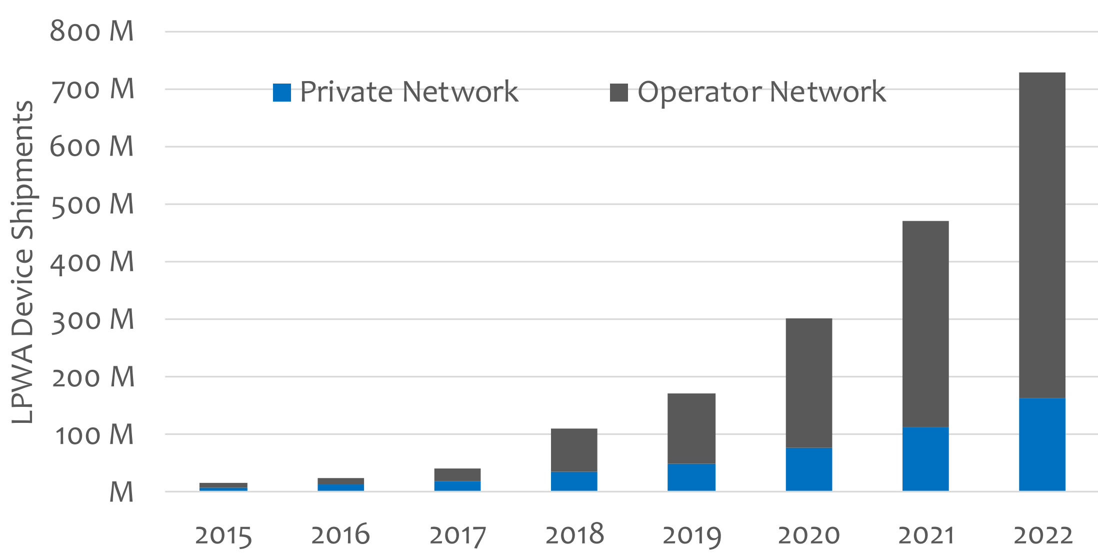

Chart 1: Forecasted LPWA Device Shipments, Unlicensed vs Licensed, 2015-2022

Source: Mobile Experts

Notably, 5G NR will not make a big impact on the low-power wide-area market. Despite popular media accounts, 5G will not be cheaper than NB-IoT and the benefits of low latency and huge bandwidth are not interesting in most LPWA applications. The one area where 5G will be interesting comes from "network slicing" which could provide a measure of guaranteed performance for an enterprise customer.

One critical point in the LPWA race is that the Chinese government is tilting the playing field heavily in favor of NB-IoT. All three state-owned mobile operators are deploying nationwide NB-IoT networks, and the government is subsidizing devices as well as semiconductors to enable NB-IoT to ramp up quickly. The central government has also set very low pricing levels for NB-IoT services, so growth in China is assured. With tens of millions of devices shipping in China during 2019 and 2020, we expect cost to come down quickly and put NB-IoT nearly on par with LoRa devices for cost.

In terms of LPWA shipments, Asset Tracking, Building Automation, and Smart Meters are major contributors to growth, with interesting contributions from other areas such as Agriculture, Consumer White Goods, and Smart Cities. Shipment growth is nicely balanced among these very different market areas.

Service revenue for LPWA networks looks quite different, as Building Automation and some Smart Meter/Smart City applications involve private use of LPWA. The leading areas for operator service revenue will be in Asset Tracking, Health Monitoring, Industrial, and Smart City applications. As new spectrum licensing options become available (such as CBRS in the US market), we expect some of the LTE-M and NB-IoT industrial segment to migrate toward private networks… during our five-year forecast window this impact will be minor.

Despite aggressive price erosion, module revenue will grow tenfold, from only $340 million in 21017 to $3.7 billion in 2022. Similarly, the semiconductor revenue for LPWA modems/transceivers/RF front ends will grow from $130M in 2017 to $1.9 B in 2022.

2 LPWA—NOT ONE MARKET BUT 7+ VERTICAL MARKETS

A few years ago, many people latched onto the idea that with LPWA technology, many different devices/sensors would be interconnected over a wide-area fabric of connectivity. The name "Internet of Things" or "Internet of Everything" implies that devices can be interconnected across many different applications.

In fact, we don't see that happening. Smart streetlights remain separate from smart trash cans, even if both are funded by the same city government. Bicycle tracking and smart meters do not use the same networks in most cases. Because the customers are separate and make independent decisions on network technology and devices, we track the following vertical markets separately:

- Industrial IoT devices for enterprise customers;
- Asset tracking devices;
- Healthcare devices;
- Agricultural devices;
- Building automation and security;
- Smart City devices, funded by municipal or other government entities; and
- Smart Meters.

Over the past three years, Mobile Experts has investigated each of these vertical markets individually, so that we can accurately predict the future application and technology trends. Overall, we see strong growth for LTE-M, NB-IoT, and LoRa in multiple areas, but other formats will be fading away.

INDUSTRIAL APPLICATIONS:

Enterprises represent one of the richest and broadest markets for LPWA devices. Industrial applications range from propane tank monitoring to grid management, water treatment, and process control. The sensors can be very different (detecting gas, temperature, humidity, vibration, or anything else), but the use of LPWA is similar for all of these applications. Some of these IoT devices will include significant on-board computing power (such as industrial robotics that work autonomously, given occasional commands from a central control point). Other devices are simple, such as the sensors monitoring propane gas tanks.

From the connectivity point of view, the questions center on how much data must be transmitted to the gateway and relayed to the cloud service, and the distance/environmental factors for the radio link.

For enterprise markets, the performance of the RF link is often not the primary factor in the decision to use LTE-M, NB-IoT, or LoRa technology. The first decision comes down to the preferred business model.

- Large industrial enterprises have a strong preference to control their data, and any option that allows for them to own the radio infrastructure will be considered first.
- Smaller enterprises that can't deploy infrastructure over a wider area are naturally inclined to use a commercial network, either based on mobile or U-LPWA technology.

The next question is ROI: Will IoT connectivity pay for itself? In a pure industrial setting, IoT connectivity is expected to reduce labor costs, capital expenses, and other primary business costs. Alternatively, IoT connectivity could increase revenue or production capacity.

Case Study #1: Oil Well Monitoring:

One obvious case for cost savings centers on oil field operations, where LPWA technology (RPMA) has found success. To illustrate the savings associated with instrumenting the oil wells, we assume an oil field with 5000 wells, each of which need to be manually checked by a technician every 30 days to be sure that everything is flowing properly and overflow tanks have not filled up.

By instrumenting pressure sensors and other devices on the oil pumps and tanks, instead of ten technicians to constantly drive pickup trucks around the area, a single higher-wage technician can monitor IoT devices and make adjustments in the field. The labor savings in this case can be undeniable… and in fact capital costs are reduced as well, because only one pickup truck is required instead of a fleet of trucks.

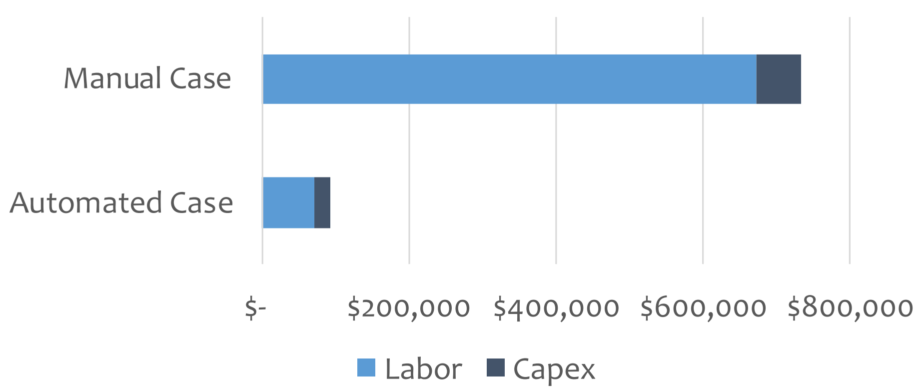

Chart 2: Cost Savings associated with oil field operations

Source: Mobile Experts

ASSET TRACKING APPLICATIONS:

Mobile Experts has investigated six market sectors where asset tracking can be achieved using LPWA technology. In particular, we've examined agriculture (tracking cows and sheep), transportation, healthcare, retail, industrial, and consumer product tracking.

The primary economic motivation in this case is simply to avoid the cost of losing the asset itself. A lost package or a cow that wandered away can result in a loss of thousands of dollars. For these high-value assets, a module in the range of $5-10 can be a sensible way to reduce loss.

Case Study #2:

The National Cargo Security Council estimates that the global financial impact of cargo loss exceeds $50 billion annually.[1] These losses are felt directly by shipping companies, costing thousands of dollars per load. Indirectly, losing an important shipment can damage a customer's reputation and potentially lose their business. By improving visibility, asset tracking can reduce the percentage of containers lost, saving reputations and dollars. In our survey, users indicated to us that the payback on Asset Tracking investment is very quick. As one example, a $250 module can track a large steel cargo container, and the high cost is paid for in the "average cost" of losses in the very first shipment.

[1] http://www.inboundlogistics.com/cms/article/the-full-cost-of-cargo-losses/

ANNUAL DATA, WITHOUT ASSET TRACKING	VALUE
TOTAL NUMBER OF SHIPMENTS	100,000
NUMBER OF SHIPMENTS LOST	1,000
PERCENTAGE OF SHIPMENTS LOST	1%
VALUE PER LOAD	$200,000
LOSS PER LOAD	$2,000

ANNUAL DATA, WITH ASSET TRACKING	VALUE
PERCENTAGE OF MITIGATED LOSS	0.3%
NEW PERCENTAGE OF SHIPMENTS LOST	0.7%
LOSS PER LOAD	$1,400
SAVINGS PER LOAD	$600
COST PER ASSET TRACKING DEVICE	$250

Figure 1: ROI illustration for improvement in lost shipments

Source: Mobile Experts

HEALTHCARE APPLICATIONS:

In our survey in the healthcare market, we found that monitoring the health of patients can be one of the most compelling applications for LPWA technology. In particular, in the US healthcare market, recent changes to the legal liability for hospitals has created a need for improved monitoring of surgical patients.

Traditionally, hospitals provide surgical services for patients, sew the patient back up, monitor the patient overnight, and release the patient to avoid the huge cost of a lengthy stay at the hospital. However, under this scenario many hospital-acquired infections (HAIs) are not diagnosed properly because the post-surgical recovery period is spent primarily at home. The patient generally checks in with the doctor after a week or two. In the traditional American health-care model, if the patient has an infection, the insurance carriers paid for the follow-up treatment, which typically is provided by the same hospital. In fact, from a cold business point of view, infections were a good thing for the hospital and there was no financial incentive for them to reduce infection rates.

However, recently the American Medicare system and other insurers have begun to refuse reimbursement of the hospital's expenses related to HAIs. Since the hospital caused the HAI through a failure to maintain a sterile environment, the insurance companies have started to say that HAIs are "not my problem", leaving the hospital to care for the patient in follow-up treatment. Magically, this change is causing hospitals to pay more attention to infection rates and monitoring the patient's health after surgery.

Figure 2 A "smart patch" for clinical monitoring

Source: Karten Design

Smart Patches are one way to monitor the patient's vital signs. These patches can keep track of temperature, pulse, blood oxygen levels, glucose levels, and other key health factors.

Our discussions with health-care professionals indicate that the use of Smart Patches may not reduce the rate of infection, but will dramatically reduce the severity of an infection that occurs after the patient is discharged. By quickly alerting the doctor that his/her patient has an elevated temperature, the patch can reduce death rates and other serious complications.

Case Study #3:

Financially, the Smart Patch is a clear win for the hospital. For a hospital that performs surgery on 1 million patients, roughly 20,000 patients will acquire an infection. The patch can reduce the cost of each infection from $20,000+ to $2,000, and also dramatically reduce the legal liability from malpractice lawsuits. So, despite a cost of $150 million for monitoring devices and nurses to oversee the data collection, the cost reduction is clear.

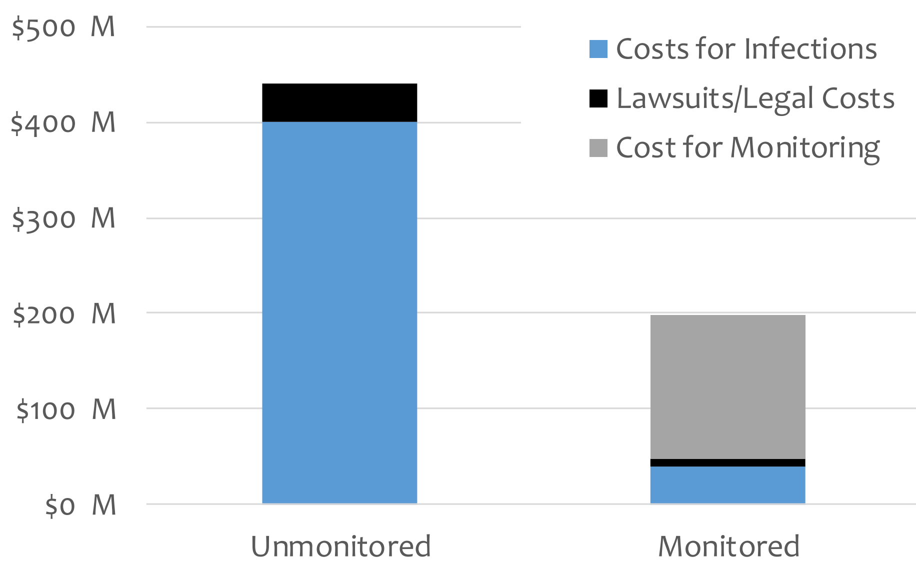

Chart 3: Cost Savings associated with health-care monitoring

Source: Mobile Experts

AGRICULTURE:

Very simple IoT devices have been adopted recently by some forward-thinking farmers that perceive a benefit in better instrumentation of their crops and fields. Two primary drivers dominate this market area:

--Cost reduction in farming operations;
--Increased production in terms of either quantity or quality.

The most common example is the use of IoT devices to monitor soil moisture. Vineyards such as Hahn and Scheid Vineyards in California have adopted moisture sensors on every vine, to optimize the watering process. With wine grapes, too much water results in poor wine flavor and too little water results in small grapes and low output. The vineyard strives for the optimal level of water to stress the grapevine the precise amount to yield high-quality wine.

At Hahn Vineyards, the instrumentation of the vineyard has resulted in incredible labor savings, cutting the labor force by half. Workers waste far less time driving to a field in order to check on status… and the quality of the wine has also increased (this is subtle and difficult to measure, but we noted that the pricing for Hahn wine has increased over the past four years).

Wineries are good examples of business concerns that are willing to invest for higher quality. We expect that as IoT devices get cheaper, we will see migration of the technology to mainstream crops (broccoli, lettuce, cantaloupes) that yield a lower dollar value per acre and which are less sensitive to precise watering, fertilizer, and other inputs.

BUILDING AUTOMATION AND SECURITY:

Traditional automation in a large commercial building involved a dozen different systems that relied on very simple sensors and control systems. Looking at today's market, some things remain constant, and other areas are changing. For example, in general the air conditioning, water, lighting, and other systems remain independent. It's rare for a single control system to manage all of these different areas.

However, some areas such as security are changing more quickly. Security is one area that requires battery-operated sensors and actuators, controlled via wireless technology. In both new construction and existing buildings, security systems are increasingly starting to use LPWA technology for the combination of ad hoc setup, long range/deep penetration, and low cost.

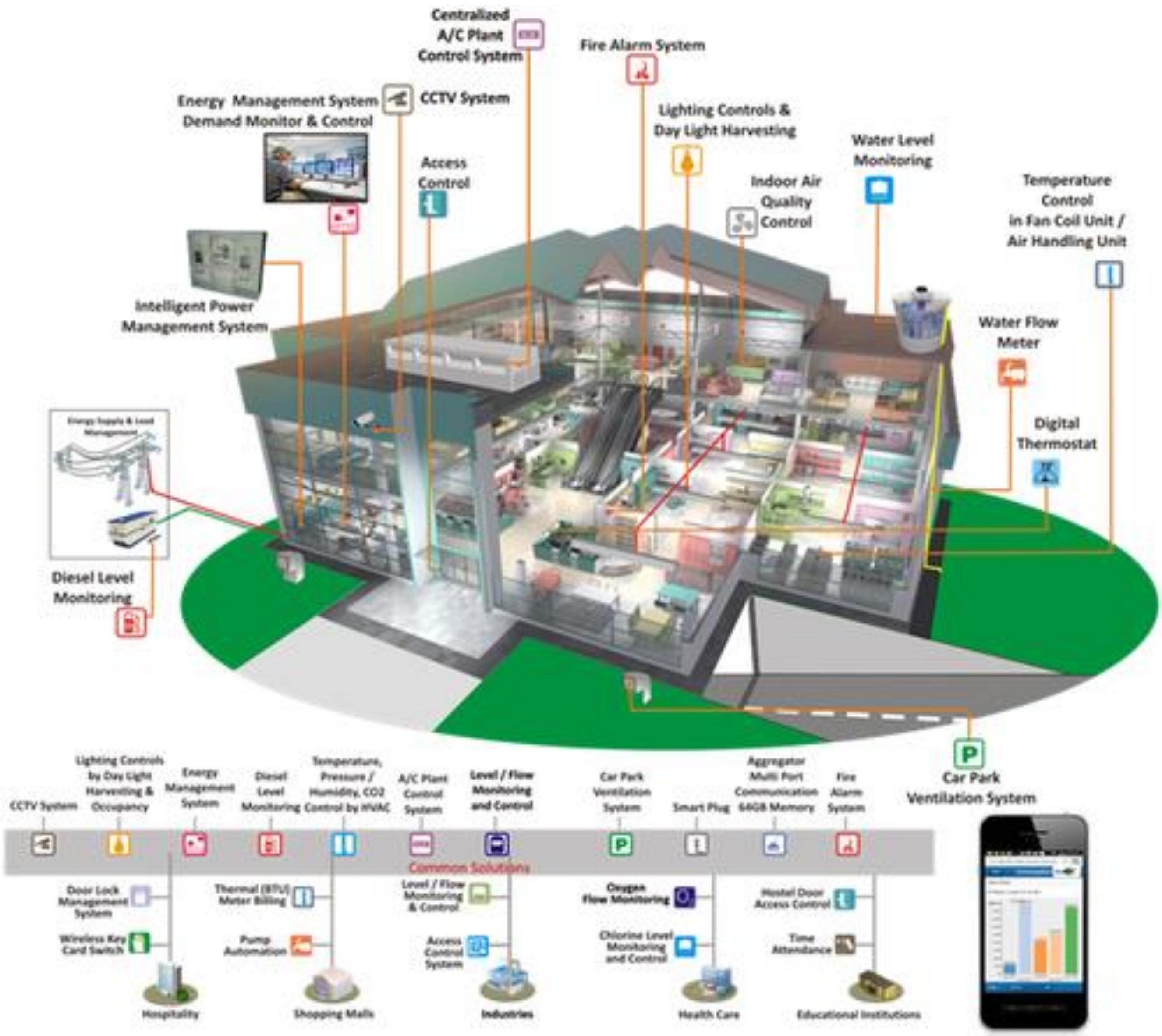

Figure 3 Various Building Automation applications

Source: Intellisys Fire And Security Systems LLP

Overall, the building automation segment moves pretty slowly. The grand vision of a unified LPWA network controlling all applications within the building does not appear to be likely, but still there will be decent growth in individual “silo” applications such as security.

SMART CITY:

Smart city applications include a wide range of use cases, starting with smart street lighting, but then branching out to waste management, parking, traffic management, and other areas. As with Building Automation, many people hope that Smart Cities will migrate toward a common, unified network for multiple applications. That's not really happening very much.

Streetlights are one successful application so far. Telensa has deployed 1.5 million street lights to date, and has developed advanced algorithms for traffic counting and light-dimming based on traffic levels, truck/car/bicycle information, as well as other features such as air quality monitoring. Smart trash-can applications are also fairly successful, with Bigbelly trash cans in thousands of cities across the United States.

Overall, the ROI can be positive for Smart City applications. Streetlight upgrades save money primarily from the upgrade to LED technology, but the connectivity can also save energy costs by dimming lights or turning lights off as needed. Smart trash cans offer a location for cities to advertise upcoming events or even to sell advertising space. The ROI is not as compelling as agricultural, healthcare, or asset tracking applications, but some specific cases can be positive for the city.

The big challenge for the Smart City market comes from dependence on the political process to approve funding for a system. In some cases, vendors are offering products without a large up-front payment, so that cities can avoid the need for new taxes or other extraordinary political processes to get started.

SMART METER:

The Smart Meter market is already fairly mature, and most large utilities have already settled on a technology choice. Once the choice has been made, changing to a new technology becomes unlikely. Today, we see 802.15.4 technology in millions of smart meters for some locations, and Chinese utilities are starting to deploy large numbers of NB-IoT smart meters due to government pressure and subsidies. But other LPWA formats may have arrived too late to capture a major share of the smart meter market.

The ROI for smart meters is clear and obvious: Automation of the data-collection process can save huge sums in terms of labor costs for "meter readers". For that reason, Smart Meters has led the IoT market in general. Large utilities can move quickly to take advantage of automation technology, and most electrical utilities have already moved to use a form of automation. The trend is currently migrating into water meters, gas meters, and others where battery-based operation is important. In all cases, the payback time on an investment is extremely quick.

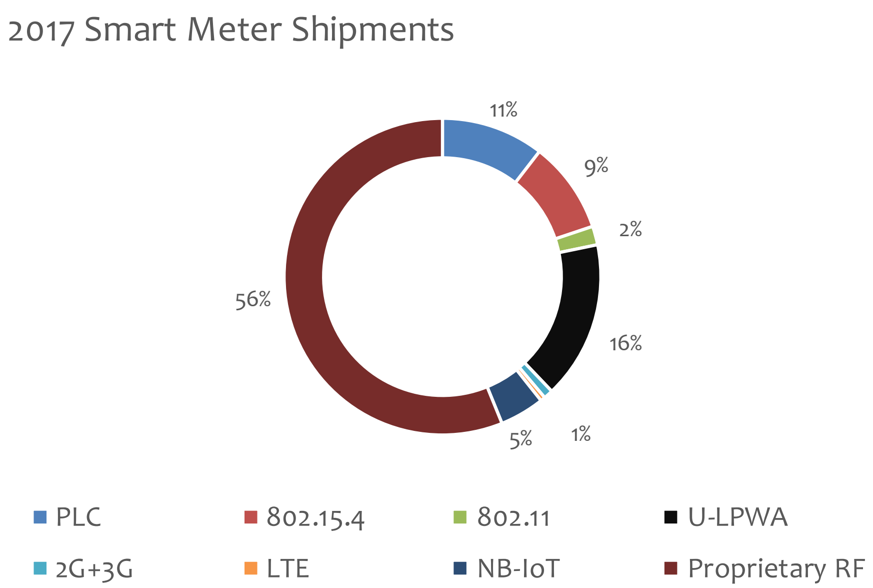

Chart 4: 2017 Smart Meter Shipments by Technology

Source: Mobile Experts Inc.

3 Technical Background: LTE-M, NB-IoT, 5G, LoRa, and Others

Background on Unlicensed Low Power Wide Area Technologies:

LPWA concepts are not new to the market despite the recent flurry of investment activities and press releases. The technologies have been available for short range use, but their extension for wide-area coverage began to develop within the last 5 years. They can be broadly divided into four classes of technologies:

1- Ultra-narrowband (UNB): these technologies operate in very narrow channels ranging between 100 – 1000 Hz. They include protocols such as SigFox, Qowisio, Telensa and Weightless-N. These technologies offer low bit rate – on the order of a few bytes per hour in order to comply with emission regulations.
2- Spread-spectrum: technologies based on direct-sequence spread spectrum (RPMA) or Chirp SS (CSS) (LoRa). They typically operate over a channel bandwidth ranging from 125 kHz to 1 MHz and offer data rate on the order of a few tens of kbps.
3- Narrowband: technologies best exemplified by Weightless-P which combines time division multiple access (TDMA) and frequency hopping spread spectrum protocol over a 12.5 kHz channel.
4- Mesh: Typically the mesh concept is used in 802.15.4 devices, using peer-to-peer communications to relay data back to a central gateway. The Wi-SUN Alliance and suppliers such as Silver Spring Networks follow this approach.

The first two categories are more popular today in terms of ecosystem support. However, narrowband technologies are relatively new and they account for some of the shortcomings of UNB and DSSS/CSS technologies.

General LPWA network architecture is relatively simple. It consists of a base station or a gateway (we will use the term base station in this report) with which field devices communicate. A network controller manages multiple base stations and processes data from devices. The base station is connected to the network controller over an Ethernet backhaul link. Multiple backhaul technologies can be used including cellular technologies[2]

[2] The low data rate in IoT applications allows using cellular technologies to backhaul data from IoT base stations. The latency in such architecture is typically too high to be acceptable for control applications, but is perfectly suitable for latency tolerant applications.

depending on application. Finally, an application server which can be hosted in the cloud provides clients the ability to manage the field devices and access the collected data.

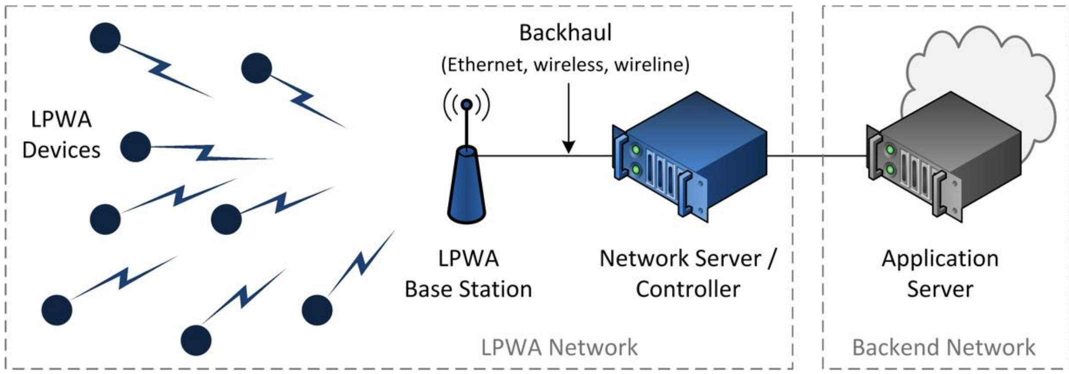

Figure 4 Basic LPWA Network Architecture

Source: Mobile Experts

LORA:

LoRa defines a physical layer technology based on chirp spread spectrum signals that spread transmitted data over a channel bandwidth of 125 kHz, 250 kHz, or 500 kHz (US only) with multiple spreading factors (SF) which define data rate and range. In the US, the data rate varies between 980 bps and 21.9 kbps. In Europe, the data rate varies between 250 bps and 11 kbps in addition to a single non-LoRa (not spread) GFSK signal at 50 kbps. LoRa complies with duty-cycle regulatory requirements and does not implement the alternative listen-before-talk (LBT) option available in European regulations. The maximum packet size in LoRa mode is 256 bytes.

LoRaWAN includes specifications to meet requirements of FCC 915 MHz ISM rules, European SRD 860 and 433 MHz requirements and China's 779 MHz rules. LoRaWAN allows for different classes of devices which makes it suitable for different application requirements:

- Class A – Bi-directional devices: This mode allows for uplink and downlink transmissions whereby uplink transmission is followed by two open windows for downlink transmissions. This mode is the most energy efficient but results in the longest latency for downlink transmissions which are limited. This mode is most suitable for uplink dominated applications without requirements for firmware upgrade.

- Class B – Bi-directional with scheduled receive slots: This mode allows for downlink transmissions to be scheduled at a specific time. The end device would have to synchronize to a beacon signal from the LoRa gateway. This mode allows for multicast messages and makes it more suitable for device firmware upgrade.

- Class C – Bi-directional with maximal receive slots: This mode allows for nearly continuous open receive window that are closed only when the device is transmitting. Power consumption is highest in this mode but provides the lowest downlink latency. This mode requires power and would not be considered where long battery life is expected.

LoRaWAN manages data rate and RF output for each end-device individually by means of an adaptive data rate (ADR) algorithm. Devices close to the LoRa gateway can transmit at high data rate and at lower RF output power to optimize the longevity of the device battery.

LoRaWAN incorporates AES CCM 128 key message encryption. It also allows for network antenna diversity as different gateways listen to the same uplink channel. LoRa gateways operate multiple channels and scale to support tens of thousands of devices. Additionally, the CSS technology enables geo-positioning through differential time of arrival techniques (DTOA).

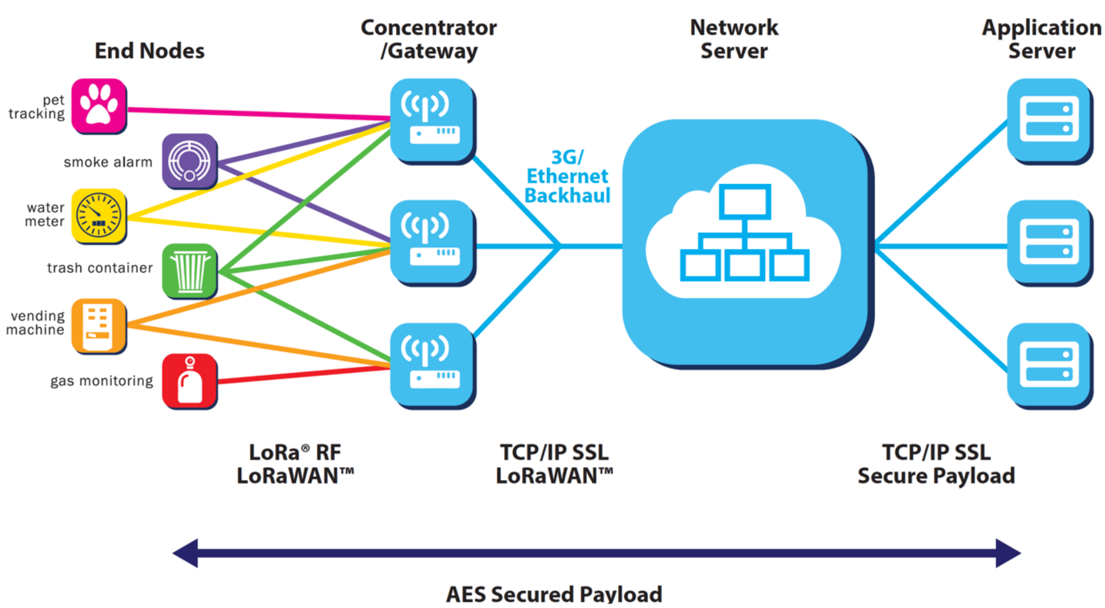

Figure 5 LoRa overall architecture

Source: LoRa Alliance

LoRa is suitable for many types of applications due to some key technology features:

- Mobility (at automotive speeds) is suitable, due to relatively wide channel bandwidth (125 kHz).
- Multicast services which enable firmware upgrade over the air.
- Multiple options for downlink service quality.
- Geolocation services, as devices can be located in the network.

LoRa spreads the signal over relatively narrow bandwidth using a relatively low spreading factor (6). The comparatively low spreading factor impacts the capacity, especially for indoor applications where there is high signal attenuation and only low bit rate (high spreading factor) can be used.

LoRa has some problems with basic features such as Firmware Over The Air (FOTA) upgrades, as well as scheduling issues in the MAC which result in poor capacity performance in dense deployment scenarios. We believe that these issues will be remedied over the next year or so as the standard evolves.

Cellular IoT Technologies:

The evolution of 3GPP standards has resulted in a series of options that directly compete with unlicensed LPWA. Specifically, GSM, 3G, LTE, LTE-M, and NB-IoT are all available for wide area IoT applications, and will certainly reduce the potential for U-LPWA options.

At a technical level, the C-IoT formats have higher performance than unlicensed approaches, mainly because of the nature of licensed spectrum. For the past 20 years, GSM, CDMA, and 3G technologies have been possible, but market adoption has been slow due to high power consumption / low battery life.

Recently, 3GPP has introduced new standards (LTE-M and NB-IoT) with great improvements in battery life, making this technology evolution suitable for many battery-powered device applications

Note that we have not covered 5G IoT in this report, because we believe that the market for low-power 5G IoT could be very small during the next five years. The standard and the implementation of semiconductors is totally unknown for low-power applications at this time. Premium applications for high reliability 5G IoT operation are possible and are covered in other Mobile Experts research on 5G.

EC-GSM:

In the 1990s, "Machine to machine" or M2M applications began with simple modules using GPRS data transfer. GPRS uses a 200 kHz FM channel in a time-domain duplex configuration, with up to 12 kbps data throughput. M2M applications coexisted with the voice communications of each 2G operator, so the network was not optimized for M2M in any way

Extended Coverage GSM (EC-GSM) is a more recent upgrade of GSM technology for IoT applications, with changes in the physical radio, the protocol layer, and higher layers to improve coverage and battery life without losing compatibility with GSM devices.

Specifically, the 200 kHz GSM channel is retained, but the ARQ (repetition) algorithm is extended in order to allow for longer range. Also, up to 52 minute EDRX cycles are allowed so that devices can go to sleep for long periods of time to save battery power.

With these changes, EC-GSM reaches a respectable link budget of about 154 dB (using a 23 dBm transmitter), but still using more battery power than NB-IoT without any other benefits.

LTE Category M1 (LTE-M):

Release 13 defines a new device category (Cat-m1, or more commonly called LTE-M) that promises further reduction in complexity and cost. It reduces the channel bandwidth, lowers the data rate and reduces transmit power among other modifications to the protocol stack. It also targets improving the system gain by 20 dB over that for current device categories to MCL over 155 dB.

LTE-M uses up to 1.4 MHz channel bandwidth, with varying allocation of resource blocks to achieve up to 1 Mbps of data throughput. The basic LTE OFDM multiple access approach is used, so that LTE-M is compatible with broadband deployments using LTE. LTE-M simply segregates some of the frequency channels and then allocates time slots for machine communications.

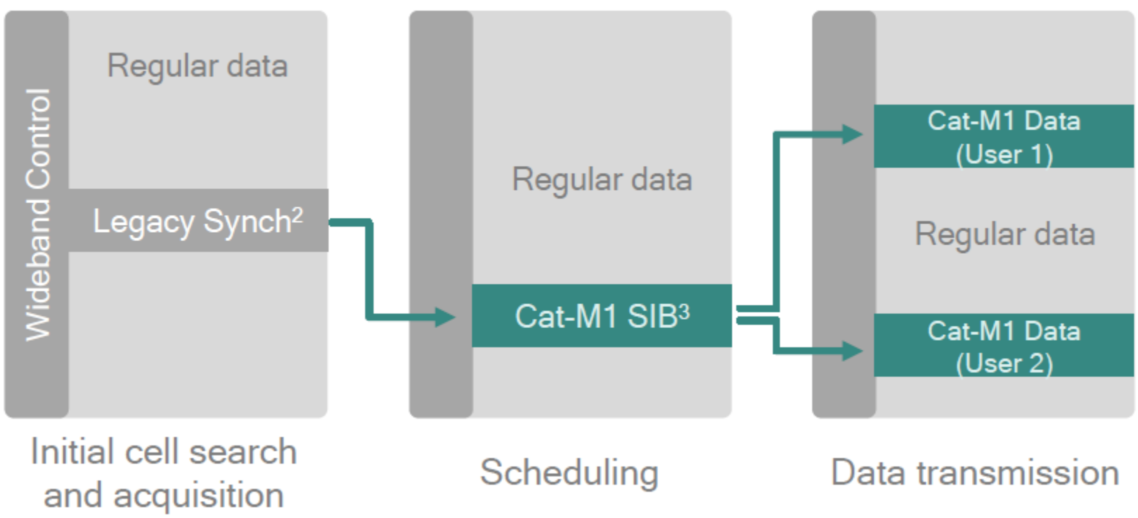

Figure 6 LTE-M shares resource blocks with wider LTE channels

Source: Qualcomm

One of the primary motivations for Cat-M is that the industry perceived a need for cheaper semiconductors. LTE-M devices can reduce the modem cost significantly, with an estimated 50% reduction in complexity compared with LTE Cat-1. When the reduction of complexity is combined with natural evolution to smaller gate geometry, Cat-M achieves significant reduction in cost and power consumption.

Cat-M achieves enough throughput to enable voice functionality in IoT applications such as automotive telematics or security applications, so Cat-M is intended as a compromise solution with higher bandwidth, that achieves a relatively low cost and complexity without sacrificing these features.

LTE CATEGORY NB1 (NB-IOT):

To effectively compete with unlicensed LPWA solutions, the mobile industry has developed a more extreme scaled-down format which uses

The roots of this effort are traced to the acquisition of Neul by Huawei who then made proposal at GERAN (the standard organization for GSM) for a clean-slate narrowband technology. This development has been enthusiastically adopted by the 3GPP community and is now well underway toward finalization. Two years ago, NB-IoT was envisioned to be finalized as part of Release 14, but the key parameters were accelerated and frozen in Release 13 last year to move the market along more quickly.

Where Cat-m1 adheres to the standard LTE channel bandwidth and is implemented within a regular LTE carrier (1.4 – 20 MHz bandwidth and 15 kHz sub-carrier spacing), NB-IoT operates in three possible modes:

1. Standalone carrier in GSM spectrum as a replacement of one or more GSM carriers, or in another spectrum allocation.
2. The guard-band of the LTE carrier by utilizing the unused resource blocks.
3. In-band operation LTE by utilizing resource blocks within a normal LTE carrier.

NB-IoT is based on OFDM, and will be set up upon but can be stripped down to a single tone transmission. A 180 kHz channel bandwidth is designated, but for the uplink, there is a choice between:

1. Single tone transmission: 3.75 and 15 kHz
2. Multi-tone transmission: based on SC-FDMA with 15 kHz uplink subcarriers

NB-IoT can work in either FDD mode or TDD mode, with FDD leading in standards maturity. Turbo codes are stripped out to reduce complexity. NB-IoT, with its lower bandwidth, offers less mobility support than Cat-M due to more susceptibility to Doppler shifts.

Overall, NB-IoT is intended to enable devices with long range performance at the absolute minimum power consumption. NB-IoT can achieve maximum coupled loss (MCL) in the link budget of about 164 dB, or roughly 20 dB improvement over standard GSM and 4-6 dB improvement over LTE-M.

	EC-GSM	LTE-M	NB-IoT
Spectrum	GSM Inband; Greenfield	Existing GSM or LTE bands	Existing GSM or LTE bands
Release Date	2016	2016	2016
Commercialization	2017	2018/2019	2018-19
3GPP Release	Rel-13	Rel-13/14	Rel-13/14
Peak DL Data Rate	74 kbps	1 Mbps	60 kbps
Peak UL Data Rate	74 kbps	1 Mbps	30 kbps
Channel Bandwidth	200 kHz	200 kHz	180 kHz
Battery Operation	OK	Good	Excellent
Link Budget (MCL)	154 dB	158-160 dB	164 dB
Network Upgrade	Software upgrade	Software upgrade	Software upgrade

Figure 7 Comparison of EC-GSM, LTE-M, and NB-IoT for technical factors

Source: Mobile Experts

The intention for NB-IoT was to enable a standard for extremely low cost devices, leaving Cat-M to handle the premium tier of the market while NB-IoT handled the low end. So far, the semiconductors released on the market have roughly the same cost for either Cat-M or NB-IoT, so the savings in lower complexity has not been seen yet. As one vendor explained, reducing the memory on the chip from 100 MB to 50 kB eliminates almost all of the cost of memory. Reducing memory further to 10 kB does not really change the cost of memory.

We believe that this situation will change, as companies like HiSilicon develop highly integrated semiconductors for NB-IoT applications and scale back processing power and RF solutions for highly integrated, high volume products. Over time, we expect NB-IoT modem/RF semiconductors to reach about $3 or less.

Technology	Benefits and advantages	Drawbacks
LTE-M	▪ Full spectrum compatibility with current LTE releases ▪ No hardware requirements to existing LTE base stations ▪ Operation on a normal LTE carrier with system bandwidth 1.4-20 MHz and 15 kHz sub-carrier spacing ▪ Allows for dedicated M2M carrier as well as overlay with mobile broadband services on same carrier ▪ Low power consumption to allow battery-powered applications ▪ Low modem cost – approximately 40% the cost of LTE-Cat-1	▪ Less smooth migration of GSM spectrum ▪ Not as optimized for low-cost/low-energy in comparison with NB-IoT
NB-IoT	▪ Fully optimized for low-energy use case ▪ Longer range and in-building penetration ▪ Operation in new narrowband carrier (180 kHz) compatible with GSM and LTE spectrum as well as greenfield deployments ▪ Allows dedicated M2M carriers as well as overlay with mobile broadband services on same carrier ▪ Approximately 25% reduction in modem cost over LTE-M ▪ Allows for greater density or number of devices supported by one base station over LTE-M	▪ Hardware upgrade to base station in some cases ▪ Limited data rate scalability

Figure 8 Overall comparison of LTE-M and NB-IoT

Source: Mobile Experts

5G NR IoT:
The 5G NR waveform allows for increased reliability and lower latency in the link, opening up the IoT market to new applications that have been restricted by these limitations in the past.

The fundamental difference between 5G NR and the other LPWA waveforms comes down to the flexibility and scalability of the data structure. In the 5G format, the numerology is scalable so that the subcarrier spacings can be set as low as 15 kHz, or any multiple of 15 kHz.

The spectrum and usage of 5G have not lined up with IoT applications so far. Implementation of IoT devices at 28 GHz will not be suitable for wide coverage, but only for high bandwidth applications. In order to take advantage of the low-latency and high-reliability features of 5G NR, we expect deployment in the 600-900 MHz range where existing mobile infrastructure will be converted to the 5G NR format.

One of the key advantages of 5G NR comes in the scalable TTI. The Transmission Time Interval can be selected for each device based on the targeted latency of the particular "network slice" that is used by a device. Shorter TTI naturally provides a lower latency, while a longer TTI results in higher spectral efficiency. In IoT applications, we expect most of the emphasis to lie on low latency so we focus on the short-TTI case.

Each slot is self-contained, with uplink, downlink, data and acknowledgements within the slot time. This means that the scaling allows for a rapid and complete transmission of an IoT burst.

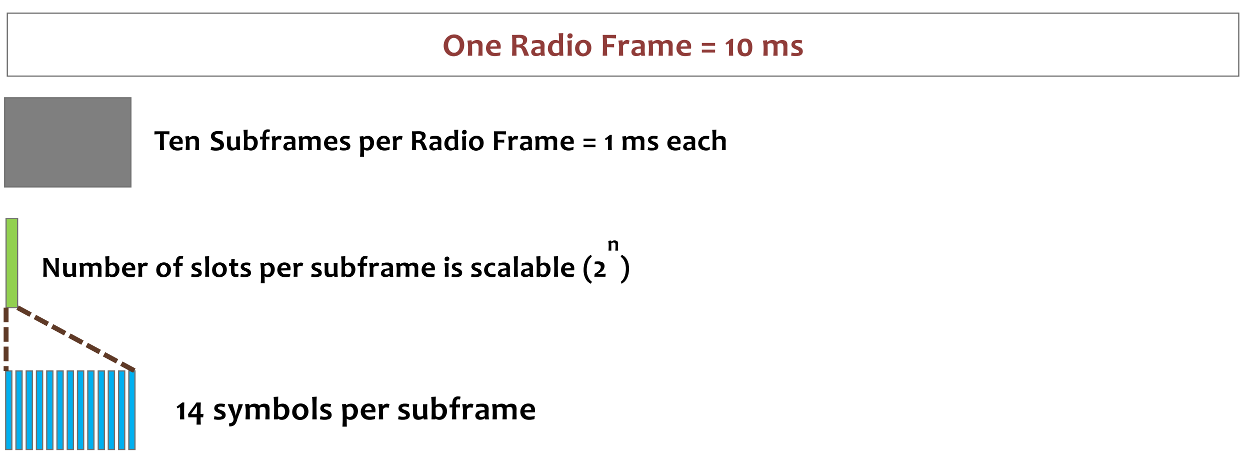

Figure 9 5G waveform overview

Source: Mobile Experts

Subcarrier Spacing	15 kHz	30 kHz	60 kHz	15 x 2^n kHz
OFDM symbol duration	66.67 microsec	33.33 microsec	16.67 microsec	66.67/2^n microsec
Cyclic prefix duration	4.69 microsec	2.34 microsec	1.17 microsec	4.69/2^n microsec
OFDM symbol including CP	71.35 microsec	35.68 microsec	17.84 microsec	71.35/2^n microsec
Number of OFDM symbols per slot	7 or 14	7 or 14	7 or 14	14
Slot duration	500 microsec or 1 msec	250 microsec or 500 microsec	125 microsec or 250 microsec	1 ms/2^n

Figure 10 Details of CP-OFDM implementation

Source: Ericsson

3GPP has advertised 5G NR as a high-reliability IoT format, indicating that 5G background traffic is designed to be resilient to "puncturing". This means that high-priority traffic can pre-empt other 5G traffic, and the other traffic will adapt with forward error correction (FEC) and repetition (HARQ) to offer the appearance of an uninterrupted link.

This feature, along with the "network slicing" of the core 5G network and other elements, puts 5G in a position to lead the market in terms of high-reliability, low-latency communications.

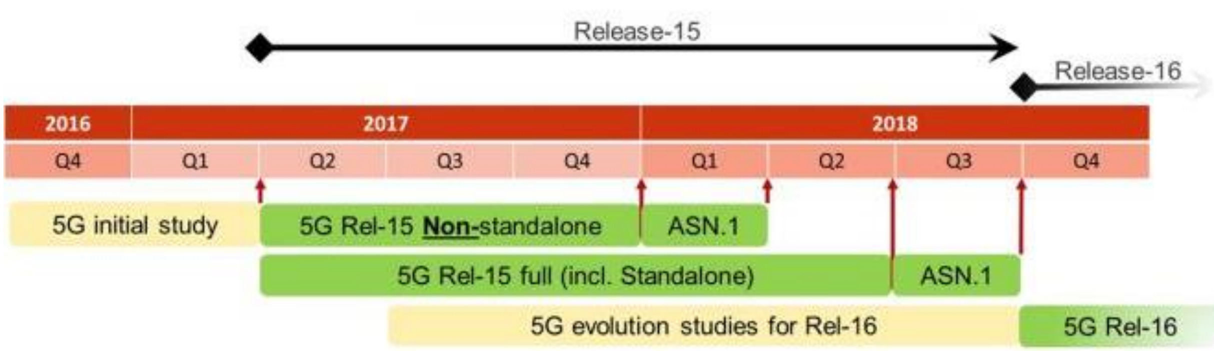

Figure 11 3GPP RAN Timeline for 5G NR standards

Source: 3GPP

Mobile Experts breaks 5G IoT into two categories based on the widely different use cases expected. Many 5G IoT devices will utilize the high bandwidth, high reliability, and low latency potential for the technology with a short battery life, transmitting at high power for best reliability. A factory automation case is one good example. In this way, one segment of the 5G IoT market diverges from the LPWA principle of extremely long battery life and only occasional transmissions.

In the Mobile Experts LPWA forecast, we count only 5G IoT devices that have an intended battery life of one year or longer, no matter what bandwidth, memory size, or computing power is embedded on the device. An example would be a security camera that only transmits a burst of high-bandwidth video when it's triggered by a motion sensor.

4 Technology Comparisons

Two years ago, the industry frenzy over various LPWA formats was incredible. Every vendor had a white paper to describe his/her connectivity format as superior to others. At the time, Mobile Experts performed a study of link budgets and other technical factors to offer clear guidance: NB-IoT offers the best link budget for long range, while LoRa offers a private solution with good link budget, good capacity and power consumption.

Differentiation in LPWA:

When customers choose an LPWA connectivity format, two factors stand out as the primary motivations in most cases: Range and Private vs Public Networks.

- All LPWA customers want long range operation and good coverage where their customers are, but for some applications an extra 10 dB of link budget is enough to trump all other factors.
- Some LPWA customers insist on private data networks, while other customers are happy to work in a carrier-deployed business model.

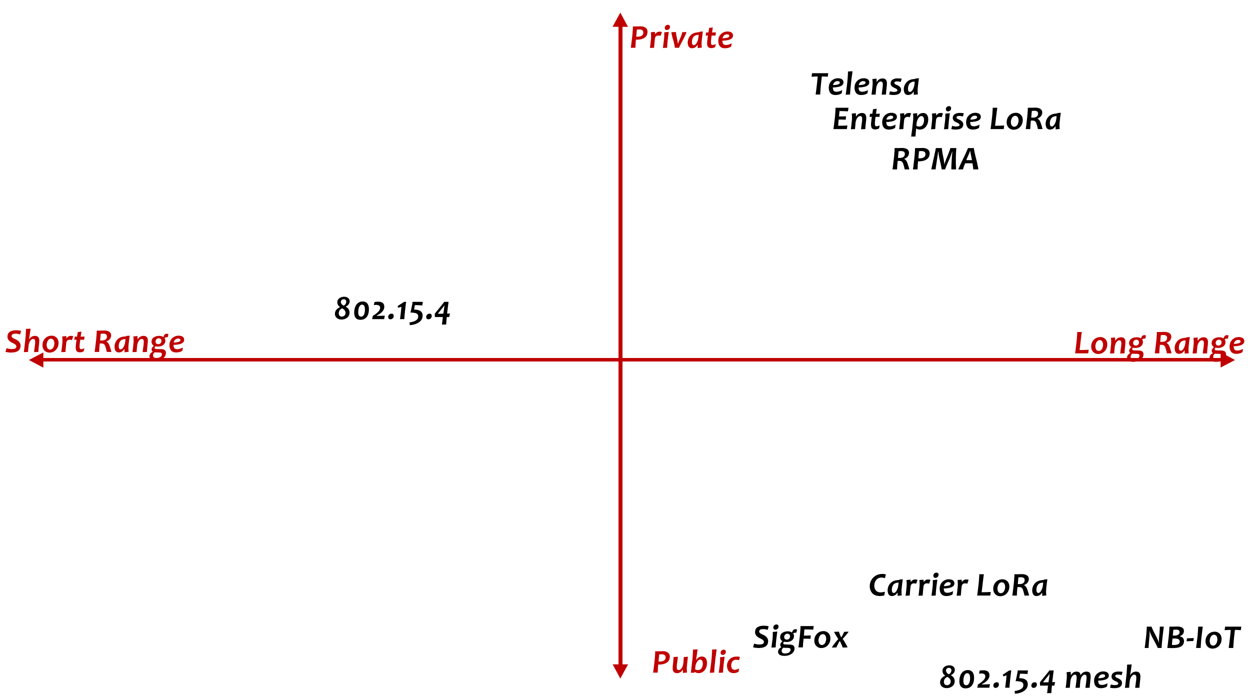

Figure 12 Ranking LPWA formats according to the two primary differentiators

Source: Mobile Experts

Diving a bit deeper, there are several other factors that can also be critical. In particular, the device cost, OTA software updates, battery life, device density, latency, reliability, and network cost can all be factors in the decision.

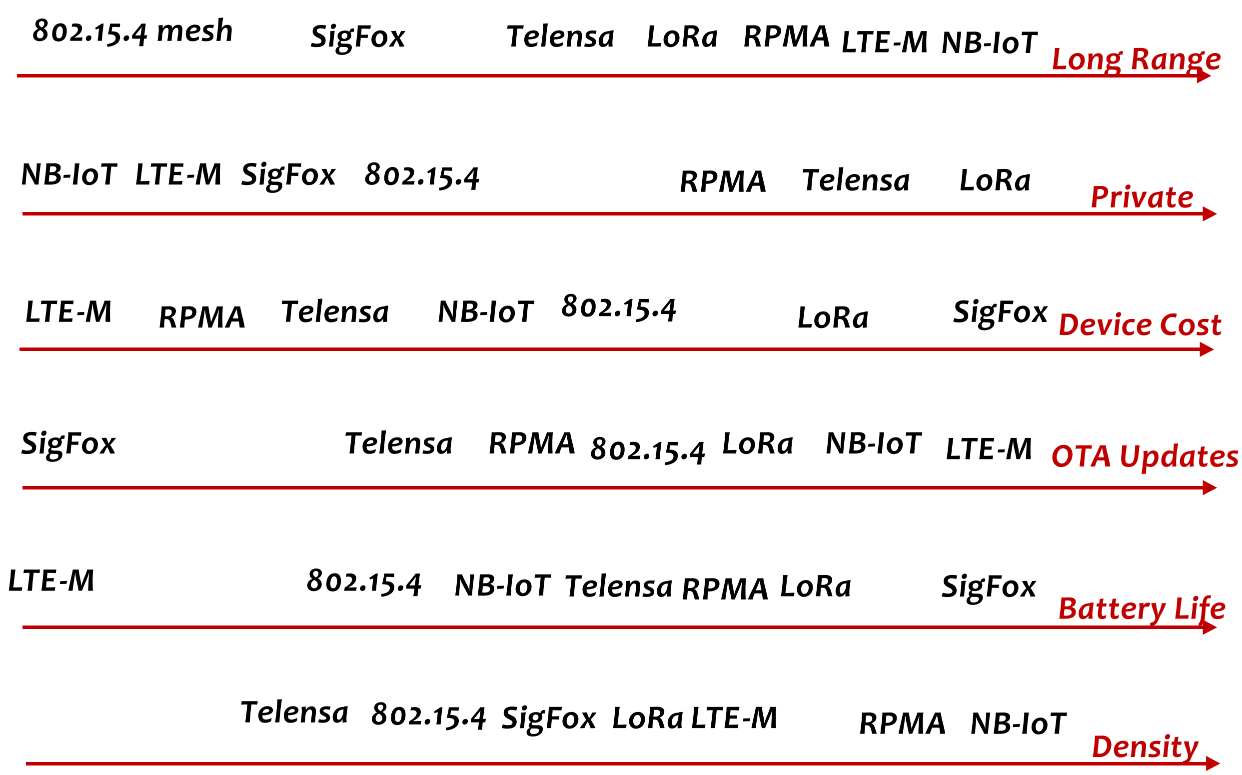

Figure 13 Six Factors that Differentiate LPWA Connectivity Options

Source: Mobile Experts
Note: 5G NR and reliability are excluded from this diagram

We've made detailed comparisons for some of these differentiation factors, to provide very specific guidance on the level of differentiation in each area.

Range and Coverage Performance

Coverage or range is a key parameter that impacts the capital and operational expenses of the wireless network, as well as the reliability of the service. We developed and compared link budgets to gain insights into the performance of LPWA and 3GPP IoT technologies.

	U-LPWA	3GPP IoT
Frequency of operation (MHz)	868 (EU) 915 (FCC) 2450 (RPMA)	900
Base station antenna height (m)	60	60
Device antenna height (m)	1	1
Interference margin (dB)	DL: 6 UL: 3	DL: 3 UL: 1
Shadow fade margin* (dB)	8.8	8.8
Wall penetration loss (dB)	25 (< 1 GHz) 35 (ISM2400)	25
***Shadow fade margin for 95% area coverage reliability based on path decay exponent n = 3.5, and shadow fade standard deviation of 8 dB.**		

Figure 14 Assumptions used for range (link budget) calculations

Source: Mobile Experts

Note that because LPWAN devices operate in unlicensed spectrum, we anticipate a higher level of interference than licensed-spectrum devices, because the interference is external to the network and is unpredictable. We assume a 2-3dB disadvantage for U-LPWA in this area, but anecdotal stories from the market imply that the interference levels in unlicensed bands can impact the link budget by 10-20 dB in some cases.

We also took 25 dB and 35 dB wall penetration loss in 900 MHz and 2400 MHz, respectively, which is typical for multilayer concrete walls as the intent is to penetrate deep into buildings where many devices are typically placed. This assumption adversely impacts the performance of RPMA which operates in 2400 MHz in comparison with other technologies which operate in sub 1 GHz spectrum.

We analyze deployments under both FCC and CEPT/ETSI requirements using actual product parameters from equipment vendors for both base stations and devices. The parameters are used to calculate practical system gain for each technology. We balanced the uplink and downlink in a manner that maximizes system gain. This generally involved using high gain omni-directional antennas on U-LPWA base stations (9 – 12 dBi) which is representative of existing deployments. The antennas on the devices have low gain (typically 0 dBi). Under FCC rules, LPWA technologies are generally uplink limited, therefore, using a high-gain antenna on the base station improves the maximum allowable path loss used in range calculations. We generally consider the base station to be mounted on top of the tower. Where this is not the case, as in SigFox's case, a tower-top low-noise power amplifier is used to compensate for uplink losses. We therefore estimate cable losses to be 1 dB or less.

3GPP IoT technologies benefit from sectored antennas on existing base station which typically have high gain (11 - 13 dBi), but the main advantage comes from the ability to support higher transmit power than U-LPWA technologies.

We calculated the cell radius using the Hata model for sub 1 GHz bands and modified COST-231 for the ISM2400 band. The clear advantage in range goes to NB-IoT due to low receive sensitivity and high transmit power. LTE-M, on the other hand, features high transmit power, but its receiver sensitivity is lower than NB-IoT which limits its range.

Note that link budget values are shown separately for EU and FCC-based deployments of unlicensed technologies. Europe and the United States have different regulatory limits. Because of this, a higher number of gateways will be necessary in Europe to achieve the same quality of coverage.

	EU – CEPT/ETSI				FCC				3GPP IoT	
	LoRa	SigFox	RPMA		LoRa	SigFox	RPMA		Cat-m1	NB-IoT
System Gain (dB)	150	144	166		161	158	172		159	173
MAPL – Outdoor (dB)	135	129	151		149	146	157		156	163
MAPL – Indoor (dB)	110	104	116		124	121	122		122	138
Outdoor range (km)	2.3	1.5	2.7		5.8	4.7	4.1		9.0	15.6
Indoor range (km)	0.41	0.27	0.24		1.03	0.84	0.36		0.91	2.76

Figure 15 Detailed indoor and outdoor range comparison of U-LPWA and LTE options

Source: Mobile Experts

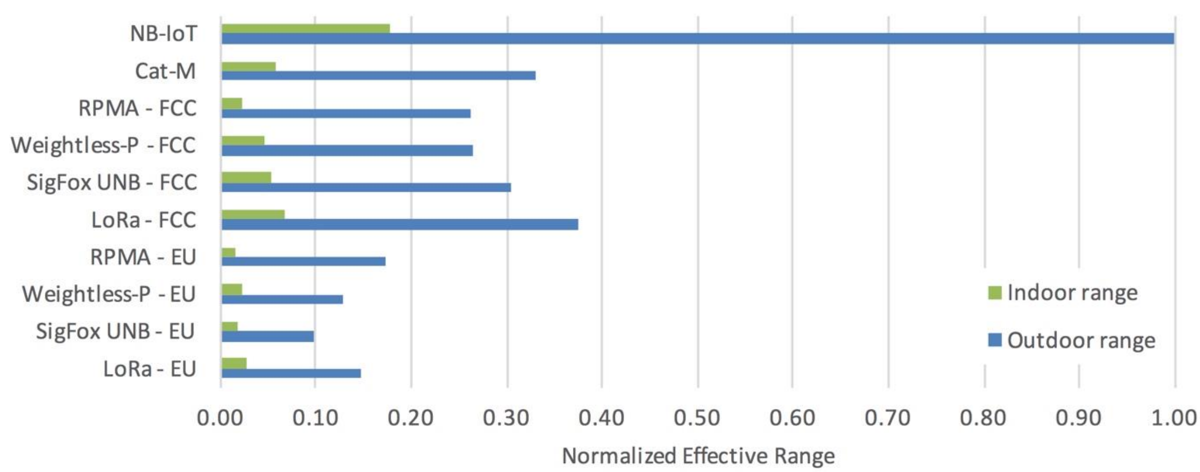

Figure 16 Range comparison for NB-IoT, LTE-M, RPMA, LoRa, SigFox

Source: Mobile Experts

The analysis points towards the following conclusions:

1- 3GPP NB-IoT benefits from favorable spectrum regulations and narrow channel bandwidth to achieve at least double the range of U-LPWA options.
2- LoRa has the longest effective range among U-LPWA technologies for indoor coverage surpassing SigFox and RPMA.
3- RPMA provides highest system gain among LPWA technologies and results in competitive range for outdoor applications even as it operates in 2400 MHz. However, high wall penetration losses at 2400 MHz result in less effective indoor coverage.
4- Under FCC rules, the uplink is the limiting path for LPWA technologies (except RPMA). Greater range could be achieved with higher device transmit power than what is typically available on market (16 dBm) or by implementing receive diversity systems on the LPWA base stations.
5- Under CEPT/ETSI rules, the downlink is the limited path due to limited transmit power. This places a ceiling on coverage range that cannot be extended farther.
6- Note that 5G IoT range and performance will depend on the frequency band chosen. In general, for the 600 MHz band used in the USA, 5G IoT range/coverage should be excellent. At 3-4 GHz in China or other countries, coverage will not be as good as NB-IoT at 900 MHz. When 5G IoT spectrum is actually identified we will be adding more specific analysis.

We have seen many claims by the industry players regarding the number of sites necessary to cover a city. This is an important consideration, but should not be over-simplified. There are a few important considerations to the infrastructure buildout comparison:

- LTE-M and NB-IoT will generally rely on the existing footprint of LTE cell sites that already exist in a city. No additional antennas or radios are needed. This means that deployment cost is based simply on the software upgrade fee paid to the equipment OEM, and the "hard costs" of climbing towers and laying out backhaul are not significant.
- Because LTE-M and NB-IoT use existing LTE towers, the 5-15 km range indicated in our link budget calculations is not utilized. LTE sites are generally about 0.5 to 3 km apart, so in the case of 3GPP technologies the antennas are pointed toward the ground. Therefore the link budget will have about 20 dB of extra margin, which improves SNR and reliability for the overall service, as well as adding the ability to penetrate for indoor coverage.
- Deploying a gateway every 4-5 miles is possible for U-LPWA approaches, resulting in very efficient deployment of infrastructure. Ingenu covered 2100 square miles in Dallas with only 17 access points, (that's better than the link budget we calculated with our benchmark antenna gains and tower heights, so we assume they improved on some of these factors). If outdoor coverage on flat terrain is desired, this works great. In hilly terrain or with urban interference, we expect problems with reliability at such extreme range.

- The use case is very important. Outdoor usage can be possible with a very sparse network, but high-quality indoor coverage requires a lot more infrastructure.

Device Density Comparison

Several companies expect to support millions of devices per access point, but in practice this concept has not been thoroughly tested in over-the-air deployments. In theory, any of the wide-area IoT formats could be stretched to its limit of capacity

The actual number of supported devices will depend on a number of factors including the characteristics of the technology and the frequency of device transmissions in addition to regulatory requirements.

	US/FCC	Europe/CEPT-ETSI
Monitored spectrum (kHz)	192	192
Channel bandwidth (Hz)	600	100
Number of channels	320	1,920
Duration of transmission (Sec)	0.4	2
Time slots per hour	9,000	1,800
Frequency-time slots per hour	2,880,000	3,456,000
Theoretical number of devices per base station (one message per hour)	960,000	288,000

Figure 17 SigFox theoretical device density estimates

Source: Mobile Experts

Regulatory duty cycle requirements have a major impact on the capacity performance of LPWA networks as they define the duration and frequency of transmissions. As a result, the capacity of a LPWA technology in the US is different from Europe or other parts of the world. This regulatory impact on performance leads to a financial impact as more cell sites will be required to support a fixed number of devices. Capacity of LPWA could be much greater, perhaps by at least 10x, if they were not subject to duty cycle limits. 3GPP technologies, on the other hand, do not have such restrictions and their capacity is determined by the interworking of the access protocol, the deployment scenarios, and the application uses cases. Unlike LPWA networks, the capacity of 3GPP networks does not depend on the region where the network is deployed.

UNB and CSS-based LPWA network elements are not time-synchronized. Transmissions from multiple devices can collide at the base station leading to errors. Technologies like SigFox and LoRa do not implement error correction codes, to save bandwidth, and are especially susceptible to errors. To compensate, these technologies implement other techniques to improve performance in a noisy channel, such as packet repetition and or diversity reception at multiple base stations--after which a network controller chooses the best data packet. The likelihood of collision increases with the density of devices, the data rate, and the duration of transmission. For example,

- SigFox transmits a 12-byte information packet during 2 seconds (in Europe) while LoRaWAN needs 2.8 seconds to transmit a 32-byte packet at the lowest bit rate (SF12, 250 bps).
- LoRa's CSS access technique has a potential of interference between transmissions using low and high spreading factors resulting from a large difference in received power level at the base station. Some reports indicate that the collisions in LoRa in Layer 2 are significant, but we believe that this is an issue which will be dealt with through software upgrades.
- Ingenu estimates that 14.6% and 26.2% of devices operating on DSSS have transmissions received below the noise floor in FCC and ETSI domains, respectively. The remainder of devices, 85% in FCC and 74% in ETSI domains, run a risk of interference due to loss of orthogonality between spreading factors. This reduces the capacity of DSSS/CSS systems that don't implement power control to ensure all signals are received at the base station at equal power level, as with CDMA-based mobile communication systems (e.g. 3G/UMTS). Large variance in power rises in large cells and for indoor devices where low data rate is used to reach the base station.
- LTE-M should be able to handle tens of thousands of devices per radio sector. So far we have not seen definitive tests to quantify the actual density possible, and of course the density for LTE-M depends on the LTE sharing mechanism chosen between broadband users and IoT users.
- NB-IoT should handle 55,000 devices per sector according to 3GPP standards.

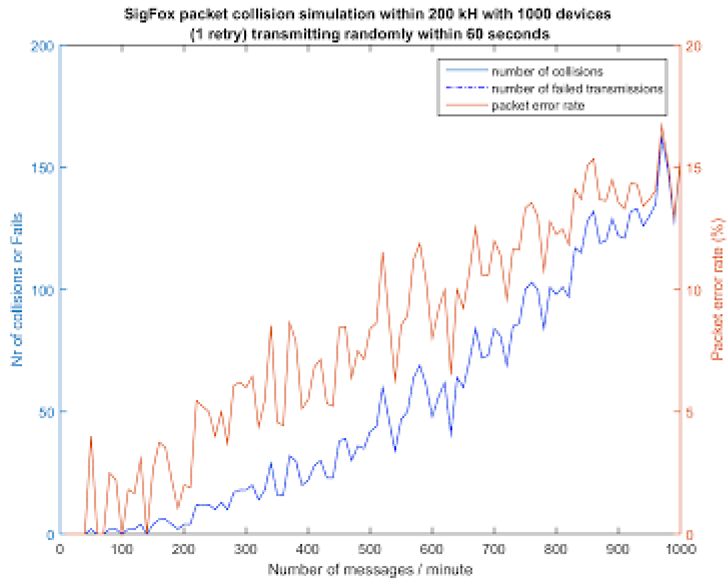

Figure 18 SigFox collision estimates up to 1000 messages/minute

Source: University of Antwerp/Maarten Weyn

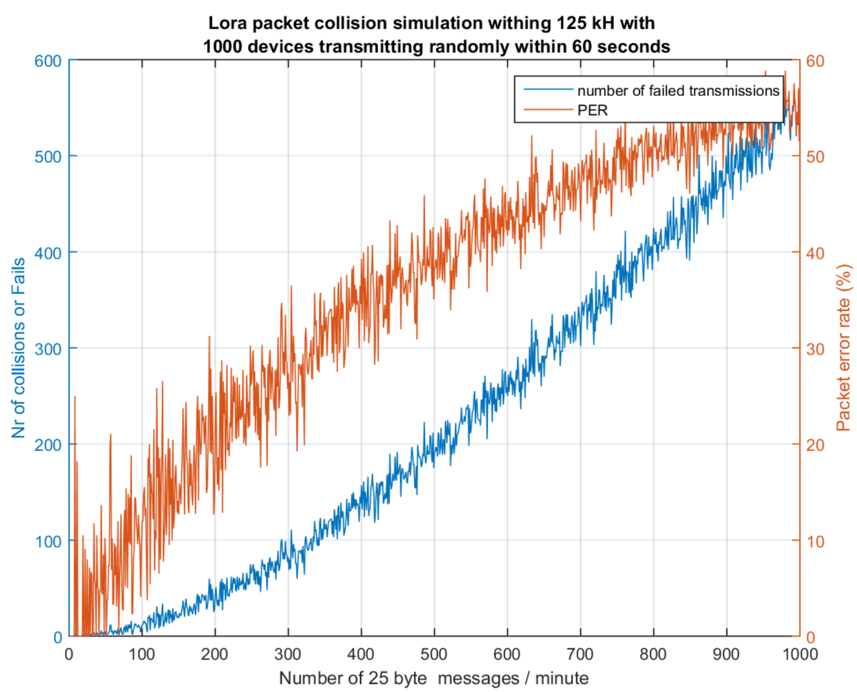

Figure 19 LoRa collision estimates up to 1000 messages/minute

Source: University of Antwerp/Maarten Weyn

Simulations such as the above Lora collision analysis indicates that a high percentage of packets will collide in this kind of unsynchronized network. As an architecture such as LoRa or SigFox is pushed toward more than 1000 messages/minute, we can expect a high packet error rate, in the range of 15% to 50%.

The number of units handled by LPWA networks is therefore a statistical calculation: the number of devices will vary depending on the deployment scenario in each regulatory domain. Some extreme comparisons have been made by individual competitors online, showing that one or two competitors will be limited to tens or hundreds of devices per AP… but we believe that all wide-area formats have a path to support tens of thousands of devices per AP.

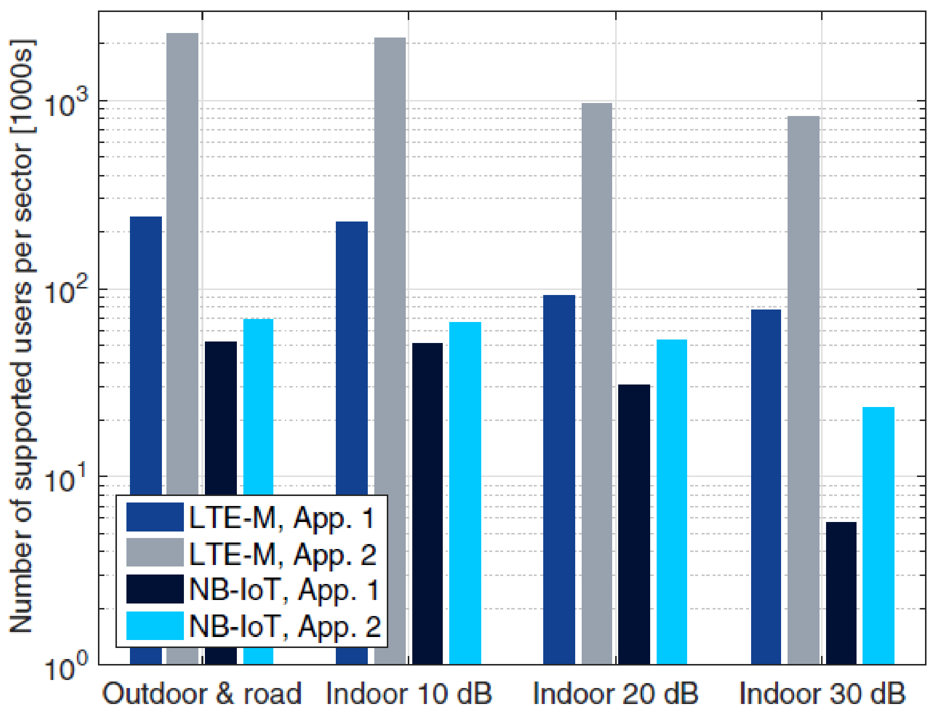

Figure 20 Device Density for LTE-M and NB-IoT in two test cases

Source: Aalborg University, Lauridsen et al.

In fact, almost all LPWA variations can now point to actual deployments with thousands of devices per access point. SigFox, LoRa, Ingenu, Telensa, and Silver Spring all have lead customers with hundreds and/or thousands of devices on individual AP.

Overall, the device density argument does not appear to be a major differentiator in the market today. It may become an area of differentiation in the future, as systems become more heavily loaded. It's important to point out that the likely outcome here is for a network to add access points, not to simply crash or lose a catastrophic number of messages. Device density, in the end, will become an economic calculation of the devices handled per dollar of capital investment.

Capacity Comparison

Turning from "device density" to pure capacity in terms of the Mbps of traffic possible per access point, we can make some clear comparison.

- The wide channel bandwidth and high spreading factor helps RPMA to achieve greater capacity than SigFox and LoRa. Put simply, RPMA supports 38 kbps/channel in their wide 2.4 GHz uplink channels, while SigFox is limited to 600 bps per channel due to bandwidth and duty cycle limitations and LoRa can do 50 kbps per channel.
- Silver Spring's combination of 900 MHz channels with wider 2.4 GHz channels can allow for data throughput in the range of 1.2 Mbps. This is reduced to the extent that Silver Spring is used in mesh network configuration, so a typical Silver Spring deployment is designed so that the mesh uses a limited number of hops. Instead of the 10-12 hops that would be theoretically possible, SSNI designs networks to use 2-4 hops for the most optimal balance of cost effectiveness and capacity limits.
- LTE-M has inherently high capacity, using a 1.4 MHz channel bandwidth and with real-world spectral efficiency likely to be in the range of 1 bps/Hz. (1.4 Mbps per channel per sector).
- NB-IoT supports 60 kbps in the uplink and 30 kbps in the downlink per channel, per sector. Clearly this is lower than LTE-M capacity so NB-IoT is targeted at higher numbers of small packets instead of applications with big streams of data. Note that both LTE-M and NB-IoT are somewhat undefined for capacity, since these protocols can expand to utilize more LTE spectrum as the number of IoT devices expands. Imagine an LTE network that allocates capacity to broadband users during the day, and reallocates spectrum and/or resource blocks to IoT devices at night.

Power Consumption

LPWA protocols are designed to enable low power consumption. This is achieved through:

1. Simple waveforms: LPWA networks are based on relatively simple waveforms that are computationally light. The baseband protocols are implemented on low-cost off-the shelf microcontrollers. This contrasts with 3GPP technologies, which have complex waveforms and are implemented on silicon as a system-on-chip (SoC). A large part of the effort in 3GPP focuses on simplifying the waveform and computational complexity to reduce the cost of silicon. Compatibility with existing

networks limits the option available to achieve this objective as manifested in the debate to harmonize C-IoT (simpler waveform) and NB-LTE (OFDM-waveform compatible with LTE infrastructure).

2. Protocol design: LPWA protocols eliminate or limit the use of functions that increase power consumption such as device paging, location update, message acknowledgement and downlink communication. They use simple forward error correction codes, if any. The protocols are designed for miniscule current draw in sleep or idle mode. Moreover, some protocols are limited in using encryption (e.g. SigFox). They also may implement non-standard addressing techniques to save bandwidth. This is a critical issue to watch for in the future as end-to-end data management is a critical issue and security needs to be addressed across the entire network. Security plays a large role in technology selection, so we expect that LPWA networks to come under close scrutiny for compliance with client requirements.
3. Limited transmit power: the emitted power limit under SRD rules is relatively low (16 dBm). 3GPP technologies which do not have this restriction are designed to operate at higher power: 20-23 dBm for NB-IoT and Cat-m1 (23 dBm used in Cat-1 devices).
4. Limited communication: LPWA devices transmit packets of a few bytes in intermittent bursts with long periods of quiet time between transmission. To achieve battery life on the order of 5-10 years, the amount of data is limited to tens of bytes per hour. The active period of a device consumes most of its power. The simpler waveform and lower protocol complexity of LPWA systems together with lower transmit power conserves energy. Minimization of sleep or idle mode current draw is critical to achieving long battery life. LPWA devices achieve very low current draw ranging on the order of a few micro amps in sleep or idle mode. 3GPP technologies aim to achieve levels close to this with NB-IoT.

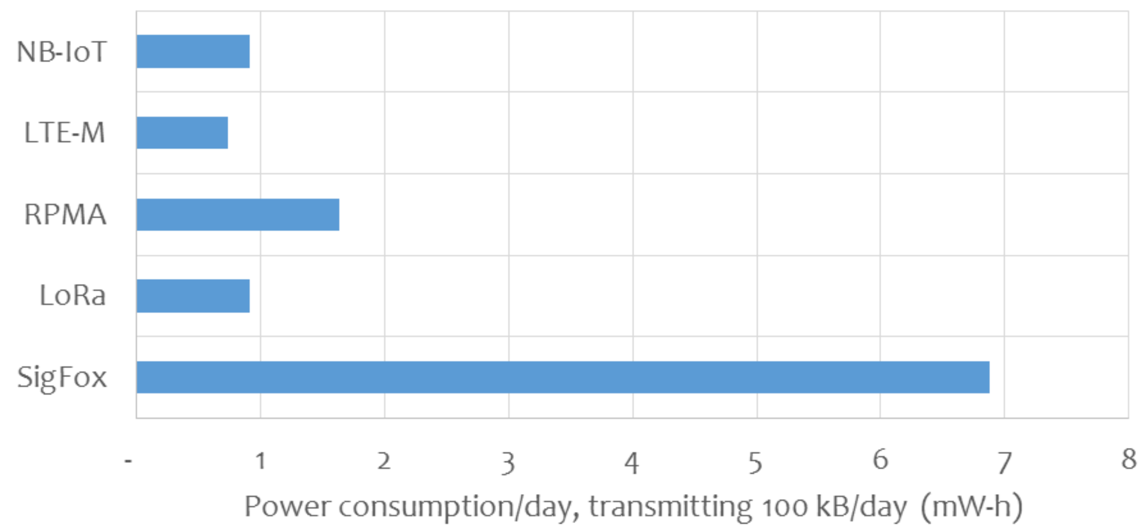

Figure 21 Power consumption comparison for U-LPWA, LTE-M, and NB-IoT options, 100 kB/day

Source: Mobile Experts

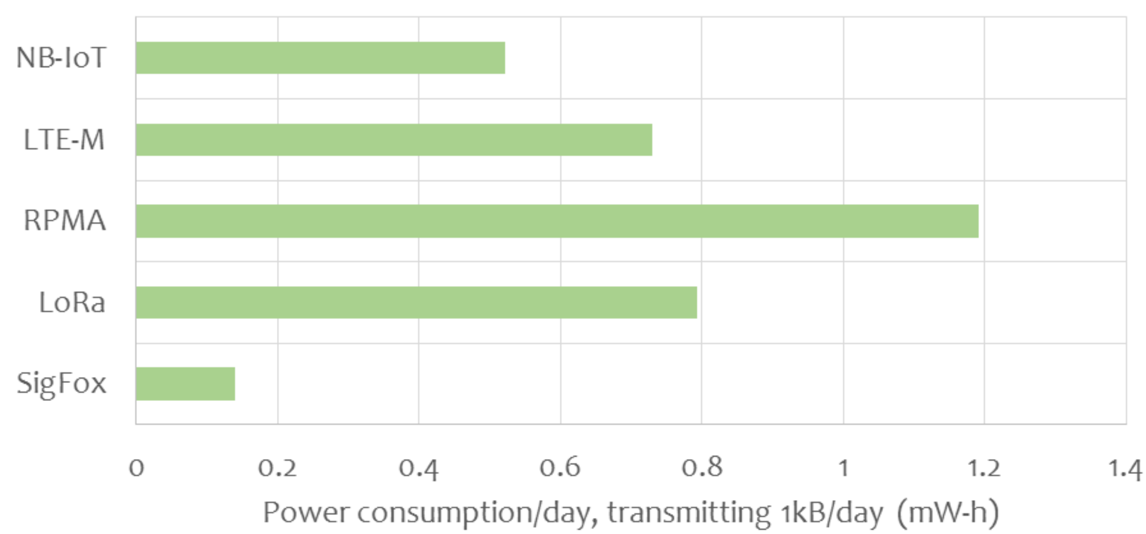

Figure 22 Power consumption comparison for U-LPWA, LTE-M, and NB-IoT options, 1 kB/day

Source: Mobile Experts

5 BUSINESS LEVEL COMPARISONS

The technical factors are now fairly well understood, and comparisons between various LPWA formats have been settled with actual field deployments. The more important comparison now turns to the business level factors. Key considerations include:

- The preferred business model of end customers. Will they accept a service offered by a network operator?
- Are there security reasons or other reasons to deploy in-house network infrastructure?
- Device cost. Is the one-time cost to buy a device a barrier to growth?
- Ease of set-up: Does the customer have any technical skills? Does the network need to be set up with "zero touch" operation like Wi-Fi?
- Field maintenance costs. Will batteries need to be recharged or units serviced in any way? Can software be upgraded over the air?
- Ease of integration with each vertical market. Does the IoT network interface with the right data formats to "plug in" to existing data analysis tools and control systems?
- Mobility. Does the end customer need coverage in a fixed location? Is the device going to move around at low speed?
- Position/location services. Is there a need for tracking the device?
- Global availability. Will the device leave the coverage area? Will the device need to function in another country?
- Ecosystem. Are there enough supporting players for big enterprises to rely on the technology? Are there open standards to allow for a rich roster of competitors?

BUSINESS MODEL

Some customers will have a strong preference for a service provider or operator to offer a monthly service, because they don't want to deploy a wide-scale network. Other vertical markets include big customers that prefer to deploy their own network infrastructure, often in an attempt to control security of the system or to save on costs.

Vertical Market	Customer Description	Preferred Business Model
Utility/Smart Meters	Large Utilities	Own infrastructure
	Small Utilities	Service provider
Street Lighting	Municipality	
	Electric Utility	Service Provider
Smart City	Municipality	Service Provider
Asset Tracking	Large Enterprises	Global or nationwide service providers
	Local Enterprises	Own infrastructure—must be easy to set up
Building Automation	Large buildings	Own infrastructure
	Smaller office buildings	Own infrastructure—must be easy to set up
Agriculture	Farm operations	Own infrastructure—must be easy to set up
Industrial operations	Oil & Gas production	Service provider
	Sensors on machines spread over a wide area	Service provider
	Sensors on machines inside a building	Own infrastructure

Figure 23 Preferred business models for several key LPWA vertical markets

Source: Mobile Experts

Standards and Interoperability

Wide-area IoT systems can be classified in two categories: Proprietary and open systems.

Proprietary systems such as SigFox, Ingenu/RPMA, and Telensa have the advantage of quick time to market and simplicity, but the market has clearly moved away from these formats in most areas in favor of more open ecosystems such as LoRa and 3GPP. In a few niche markets, Ingenu and Telensa have held on, mainly because these small companies have focused on data formats for the niche customers that make the connectivity extremely easy to integrate with existing data and control systems.

Open systems allow for multiple vendors, using standards to govern interoperability. LoRa, LTE-M, and NB-IoT fall into this category. We had listed LoRa as a proprietary system two years ago, because Semtech had developed the radio and was the only supplier of semiconductor devices. However, Semtech has done a very effective job of standardizing the radio interface and licensing their key intellectual property to STMicroelecronics, On Semiconductor, Microchip and Atmel, to create a robust group of suppliers.

All 3GPP-based standards are by definition "open" since the arrangement of the mobile ecosystem is all based on standard interoperability for multiple suppliers.

Time to Market

Three years ago, SigFox and Ingenu had a good position in terms of time to market. The mobile formats were not ready for market, and customers started experimenting and deploying solutions based on unlicensed LPWA. However, today the time-to-market advantage is not as clear. NB-IoT chipsets are available off the shelf, and NB-IoT networks have been deployed nationwide in some countries. In fact, we could argue that time to market is now faster for 3GPP formats than for the unlicensed options, mainly because the coverage for LTE-M and NB-IoT is much greater than LoRa, SigFox, or RPMA coverage.

Entrenched Customer Relationships

Each vertical market has unique data structure, unique business considerations, and and of course unique product requirements which give existing vendors an advantage. In LPWA, some existing vertical markets are already captured by specific connectivity types:

- Ingenu has done a great job of penetrating the market for sensors on wellheads in the oil & gas production market. In West Texas, as well as a few other pockets in the USA, Ingenu has established widespread coverage where no cellular coverage exists. The oil & gas customers are familiar with Ingenu now, so the barriers to entry are growing for other technologies.
- Silver Spring/Itron has latched onto a few key customers in the Smart Meter market (Florida Light & Power, PG&E, etc). Because these companies have now deployed more than 20 million smart meters using Silver Spring, it's inconceivable for any other technology to swoop in and replace SSNI.
- Telensa has deployed more than 1.5 million streetlights using their UNB technology, and has found that interoperability with existing streetlight and data collection/control systems has become a barrier to entry for their competition. As Telensa has been focused on street lighting market for years, they have built up expertise in terms of interfacing with the city's systems, and they believe that this element will prevent competition from breaking in.

These examples are compelling at a local level, but on a global scale these pockets of coverage are unlikely to expand into global domination. We expect that a local utility that has chosen Silver Spring/Itron for smart meters will continue, but the momentum for the 802.15.4 based Silver Spring product has stopped, and we don't expect many new customers to adopt it instead of LoRa or 3GPP. In streetlights, Ingenu might be able to continue growing—not because of superior connectivity, but because of superior service to the unique nature of streetlight control and monitoring systems.

Global Roaming

3GPP standards are the same worldwide, and to the extent that mobile operators can agree on a common frequency band for operation (e.g. the 900 MHz GSM band), LTE-M devices can roam worldwide easily. Applications such as tracking of large shipping containers will benefit from this kind of global service. LPWA devices will need to support at least two or three frequency bands to roam internationally, with intelligence to recognize the country of operation so that the device can adjust power levels and frequency band to the local network. This is not a major barrier, but we believe that service availability and infrastructure coverage in all countries worldwide is going to be difficult for all U-LPWA options.

LoRa is in the best position to put together a global coalition of service providers that allow LoRa roaming, but even in this case it's clear that 10 years of infrastructure deployment will be needed to come anywhere near the coverage of LTE networks today. Even if the radio coverage is established, LoRa will need to come up with global roaming agreements so that device revenue sharing can be possible. The cellular industry has a lengthy head start in this regard.

Device and Network Cost

Unlicensed wireless options are generally cheaper than licensed wireless, although recent subsidies for NB-IoT in China are starting to upset the equation. In fact, semiconductor, device, and network subsidies have put NB-IoT on par with unlicensed alternatives in terms of cost in China.

The cost comparison can be viewed in two primary ways:

1. **Module Cost:** By 2020, we expect pricing for the basic connectivity modules to stabilize at roughly these levels:
    a. SigFox: $2.00 (lack of volume will be a hindrance)
    b. LoRa: $2.50
    c. Ingenu: $5.00 (lack of volume will be a hindrance)
    d. Silver Spring: $7.00
    e. LTE-M: $7.50
    f. NB-IoT $5.00 without subsidies
    $2.60 including impact of Chinese subsidies

2. **Infrastructure Cost:** Cost for the enterprise or operator is often more highly dependent on the network cost, not device or semiconductor costs. At least in vertical markets where the end user pays for the portable device, the infrastructure cost becomes a factor.

   The cost of the gateway/access point itself is actually small compared with the cost to set up backhaul, a tower or pole for the antenna, and local power. Unlicensed LPWA gateways are straightforward boxes that will cost between $1,000 and $4,000. The cost to set up a local site can reach about $20K for the simplest cases and up to $400K for a city site where legal entanglements make access difficult.

   On the other hand, LTE-M and NB-IoT deployment generally consists of a software upgrade to an existing LTE radio system. In some cases (as with the China Telecom and China Mobile deployments), NB-IoT required hundreds of thousands of new base stations. However, in other countries the software upgrades are working fine, and we estimate the cost for the operator to be less than about $1,000 per site location.

   Overall, the cost per site will be lowest in the case of LTE-M and NB-IoT. Exceptions to the rule: Areas with no cellular coverage, and areas with old legacy 2G/3G equipment that cannot handle LTE-M and NB-IoT.

SUMMARY ON DIFFERENTIATION

The market has quickly consolidated down to two primary choices for high volume IoT, and a string of secondary choices for special cases. LoRa and NB-IoT are the clear winners, with open ecosystems, low costs, and good performance. LTE-M, Silver Spring 802.15.4, RPMA, and Telensa UNB are moderately successful with applications that depend on them.

	PRO	CON
3GPP / Cellular	▪ Licensed spectrum provides higher reliability ▪ Standard-based technologies ▪ Interoperable networks and devices ▪ Existing infrastructure: towers/physical assets, backhaul, network centers reduces build out costs for incumbent service providers ▪ Longer range than U-LPWA	▪ Traditional 2G/3G/4G solutions consume too much power ▪ Time-to-market: NB-IoT/LTE-M about 5 years behind U-LPWA ▪ Operator business model and market approach leads to higher cost base than U-LPWA ▪ High cost for devices

	▪ Longevity: MNOs are stable entities providing high assurance on business continuity over the life of device (years) ▪ Downlink and bi-directional communications unaffected by regulatory duty cycle requirements ▪ Potential for global roaming	
U-LPWA	▪ Technology is available now ▪ Agility: nimble entities can cater to different requirements and business models ▪ Enables private networks – can be deployed anywhere ▪ Optimized for sensor applications; excel in low-power applications dominated by long idle cycles ▪ Quick to deploy: light infrastructure with on-demand spot service ▪ Low Cost	▪ Proprietary technologies (except for LoRa) ▪ Prone to interference in unlicensed spectrum ▪ Regulatory restrictions limit range and capacity performance ▪ Lack of global harmonization on spectrum means that LPWA limits roaming across different markets

Figure 24 Pros and Cons for 3GPP and U-LPWA

Source: Mobile Experts

6 OUTLOOK FOR U-LPWA, LTE-M, AND NB-IOT

The growth of the LPWA market is undeniable… key segments of the market are doubling each year, and the potential in some vertical markets could be virtually unlimited.

We have reduced our LPWA forecast about 10% over the past year, from 560 million devices in 2021 to about 500 million. This change reflects the delays involved with development of the business models, not any issues with the technology. In fact, the NB-IoT push in China is responsible for strong growth in the NB-IoT segment, while in other areas the LoRa ecosystem is growth as quickly as expected. Telensa, 802.15.4, and LTE-M will contribute healthy growth within their respective areas of focus, but many others such as SIGFOX, Qowisio, Weightless, and Ingenu are likely to fade away over the next few years.

5G IoT will not become a significant part of the LPWA market during the next five years for two reasons: 1) it's not expected to be any cheaper than NB-IoT, and 2) the latency and reliability benefits of the 5G waveform do not justify the choice of a more expensive technology, except in some low-volume specialty applications.

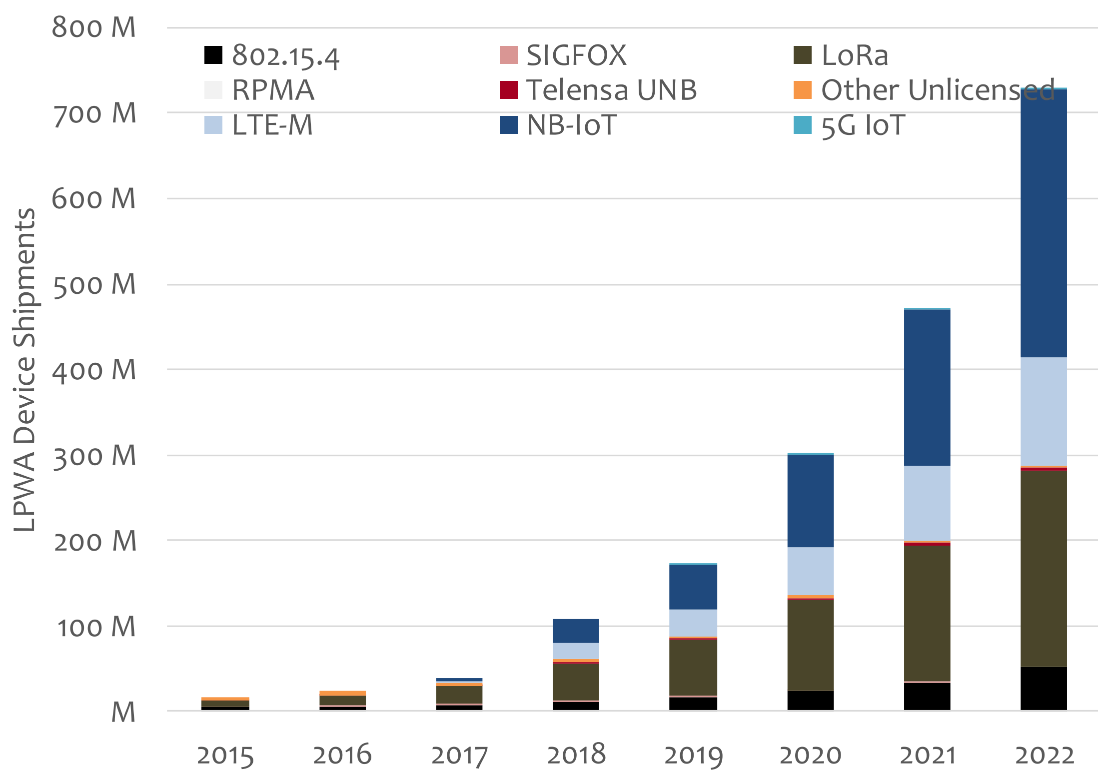

Chart 5: LPWA IoT Device Shipments, by technology, 2015-2022

Source: Mobile Experts

It's a pretty even split in the long term between licensed and unlicensed LPWA technologies. LoRa, 802.15.4, and Telensa fall in the unlicensed camp and will grow to roughly 400 million unit shipments in 2022. LTE-M, NB-IoT, and 5G IoT together will account for another 500 million shipments in 2022.

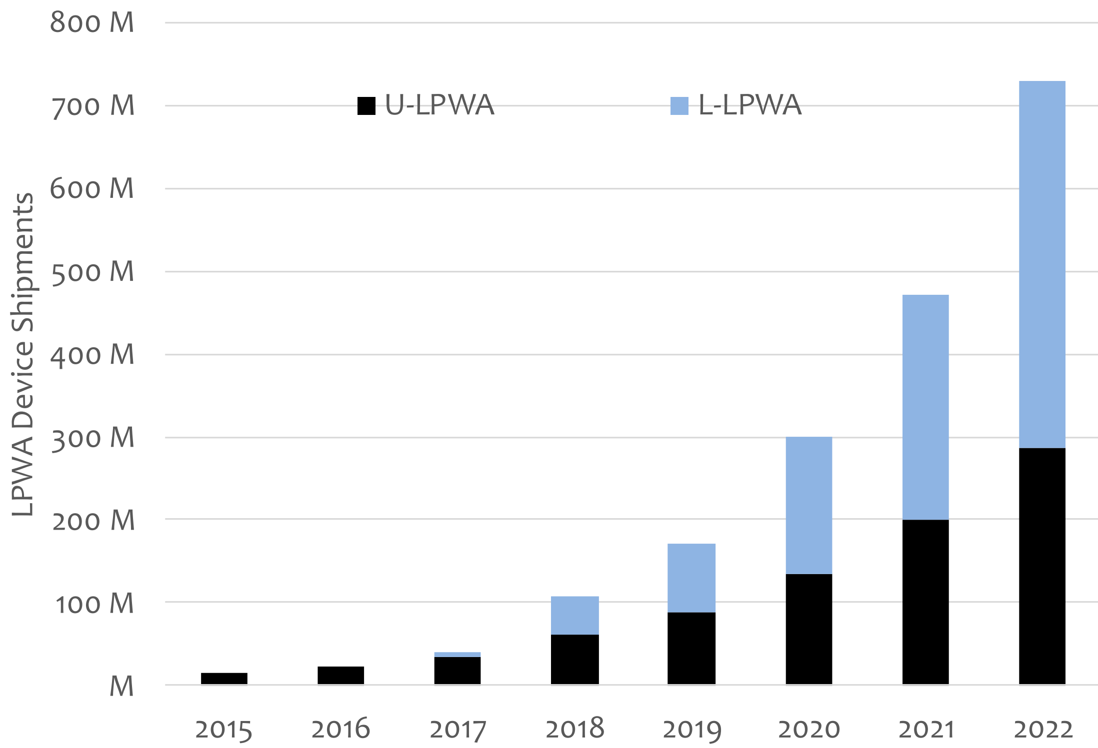

Chart 6: LPWA Device Shipments, by licensed/unlicensed, 2015-2022

Source: Mobile Experts

The early development of the market was based on mature vertical apps such as smart meters. However, as other applications reach maturity we will see health care, building automation, smart city, and other use cases expand the market steadily to become a multi-faceted, balanced ecosystem.

Secondary applications will include Agriculture, Fleet Management, Industrial, and Consumer White Goods applications. These smaller vertical markets have specific needs that can be unique, allowing for end user deployment of a mini-network to address the need.

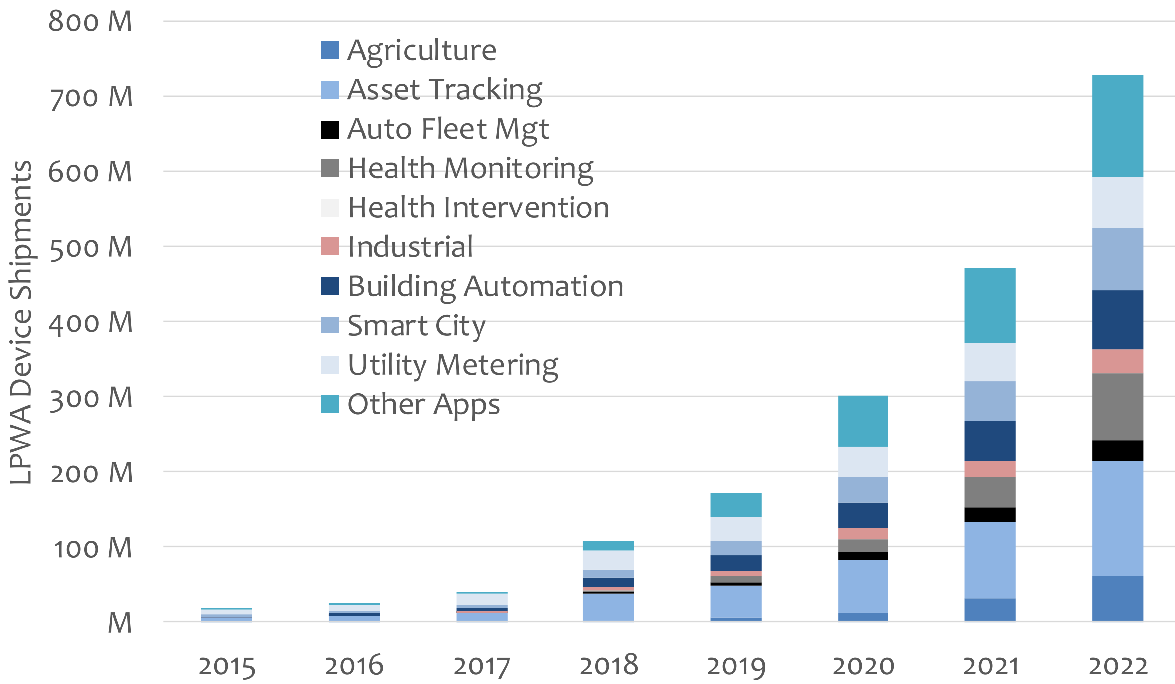

Chart 7: LPWA Device Shipments, by application, 2015-2022

Source: Mobile Experts

Open LPWA ecosystems are the clear winner. Despite an early lead by Sigfox and good performance by other proprietary networks, in a large and diverse market it's simply not possible to keep up with an open standard that allows innovation by hundreds of different companies. LoRa and 3GPP/cellular formats are both considered open formats in the sense that they allow for multiple companies to participate…the customer can buy services, infrastructure, devices, modules, or semiconductors for a variety of players, and the rich diversity allows for growth in the wide market.

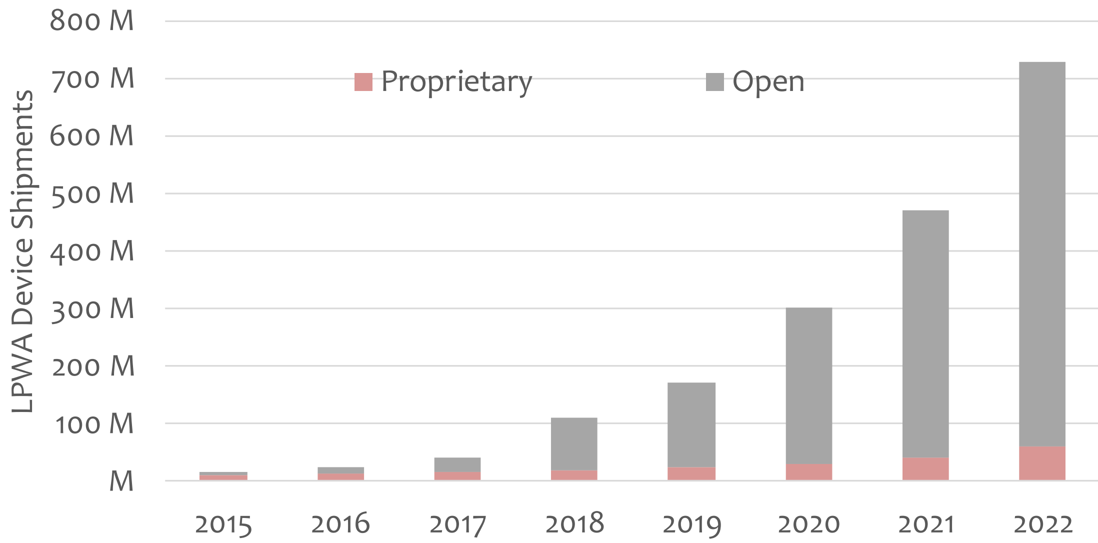

Chart 8: LPWA Device Shipments, open vs. proprietary, 2015-2022

Source: Mobile Experts

LPWA DEVICE INSTALLED BASE

Because IoT devices are generally intended to last for years, the installed base will grow quickly. Not many devices will be taken off the market…they will generally accumulate in the field, so we will quickly see the total grow to more than 1 billion units.

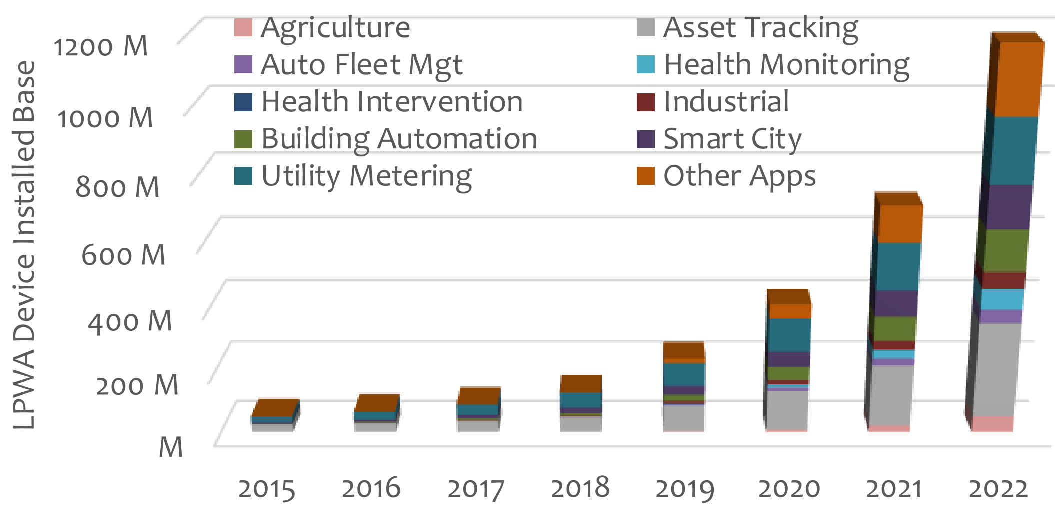

Chart 9: LPWA Device Installed Base, by application, 2015-2022

Source: Mobile Experts

Service Revenue Forecast

The LPWA market is interesting, because some LPWA devices will involve a "service tariff" or monthly fee for access---but other devices will operate freely on private infrastructure. One simple example is the use of LoRa devices in an industrial building, to collect simple data about security and operations. The building owner doesn't want to pay a recurring fee. He simply wants to set it up like a Wi-Fi network and use it.

About 60-75% of the market will be subject to service fees in some way, because all licensed devices (so far) work through mobile operators, and a large proportion of unlicensed devices work through an operator such as Comcast, Senet, or Telensa.

In fact, a large number of applications derive value from the oversight of a network operator. Cargo containers that are tracked across the country need a mobile operator's reach—and in fact when the container travels overseas, the mobile operator has a roaming agreement with the next country in line. Small utilities, farms, and businesses need somebody to manage the network, including radio maintenance, core network connectivity, and security/software updates. Running an entire network is still too complex for most customers to "plug and play".

Today, the strongest segments are in Asset Tracking, with interesting growth in Consumer White Goods, Industrial, and Smart Meter applications. The installed base will grow quickly as shipments are doubling in some market segments on an annual basis. Overall, we see the

LPWA service opportunity growing into the range of $5B by 2022. To put things in perspective, this is still pretty small compared with the 1.1 trillion dollar mobile market.

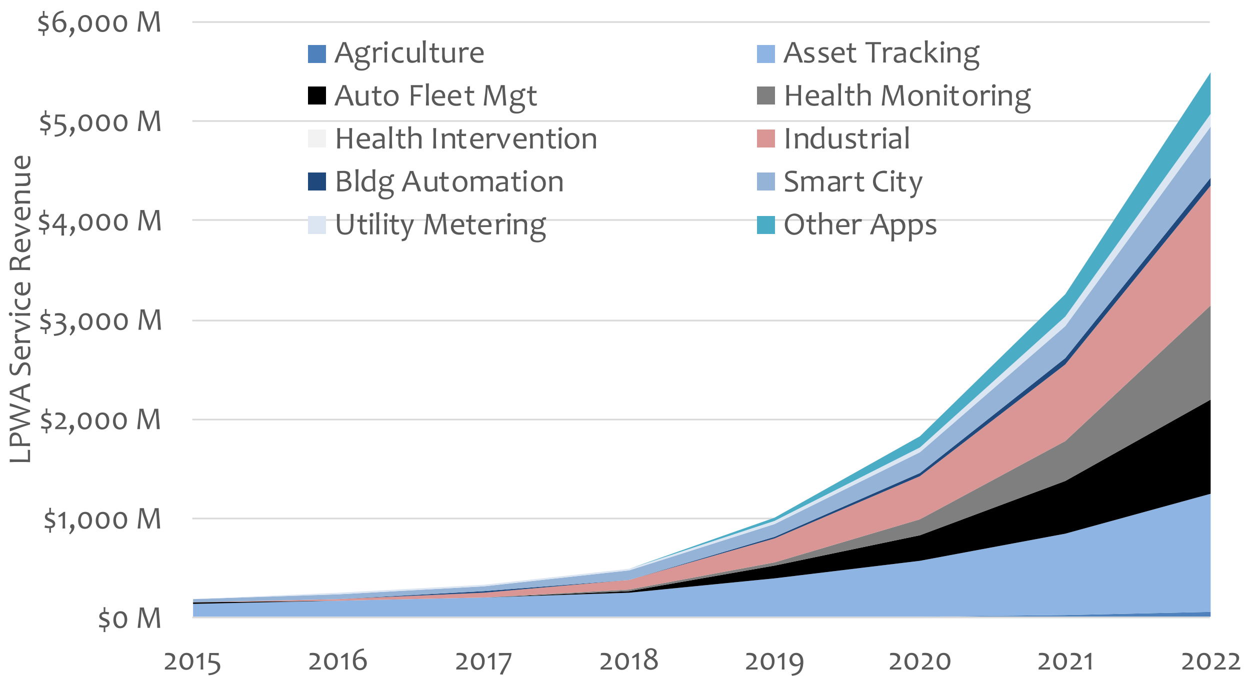

Chart 10: LPWA Service Revenue, by application, 2015-2022

Source: Mobile Experts

Module Revenue

IoT devices vary widely from one application to another. A $1000 drone can include multiple radios, while a simple door lock sensor can include a connectivity module worth less than $2.

Rather than track the value of the sensor device, drone, car, or other system-level platform in which the IoT module is embedded, we track the modules themselves.

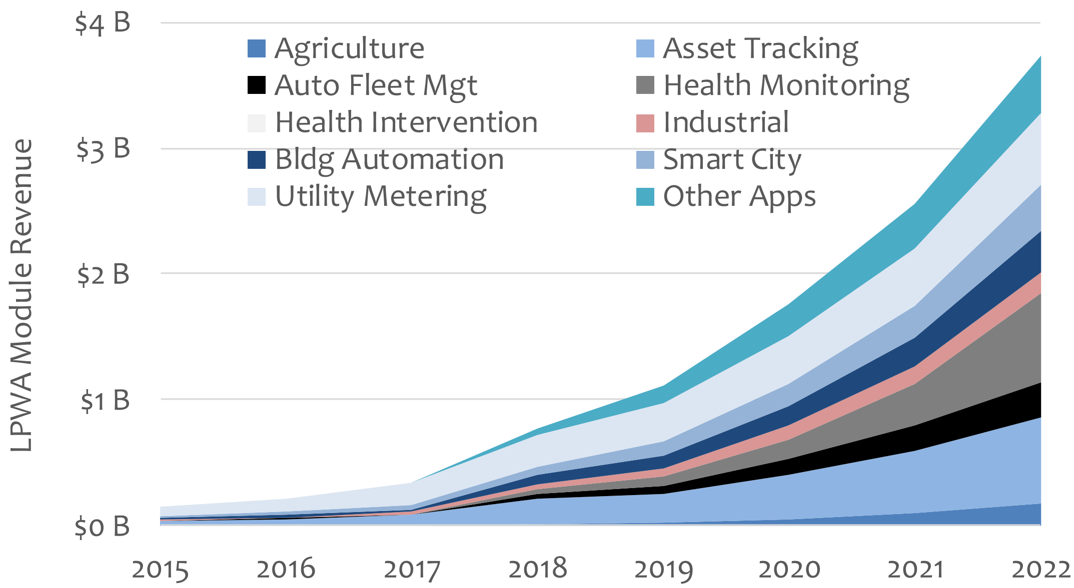

Chart 11: LPWA IoT Module Revenue, by application, 2015-2022

Source: Mobile Experts. Note: Including connectivity module costs or

SEMICONDUCTOR REVENUE

Stripping the LPWA market down to its most basic components, it really comes down to the basic modem/MCU and the RF connectivity. Each technology has a basic cost for the modem/MCU function and RF transceiver, based on the complexity of the radio protocol. The licensed technologies tend to be more expensive, with higher overhead in the modem due to complex coding, as well as a hungry patent royalty pool to feed. The RF solutions in LTE-M and NB-IoT are also provided as discrete devices, due to the higher output power of the radio. (At higher RF power GaAs amplifiers and discrete RF filters are often used for best efficiency and linearity performance).

In unlicensed modules, lower transmit power levels allows for integration of the MCU/modem/RF all into one CMOS chip. Obviously this allows for lower costs. We expect to see some NB-IoT and possibly 5G IoT solutions scaled down to lower power as well, to take advantage of these cost savings despite the tradeoff in range.

It's important to note here that the cost of NB-IoT semiconductors is subsidized by the Chinese government. The R&D and roughly half of the recurring cost of the NB-IoT chipset is covered by subsidies, so the revenue for NB-IoT chipsets is shown in the two charts below in two ways: with and without subsidies.

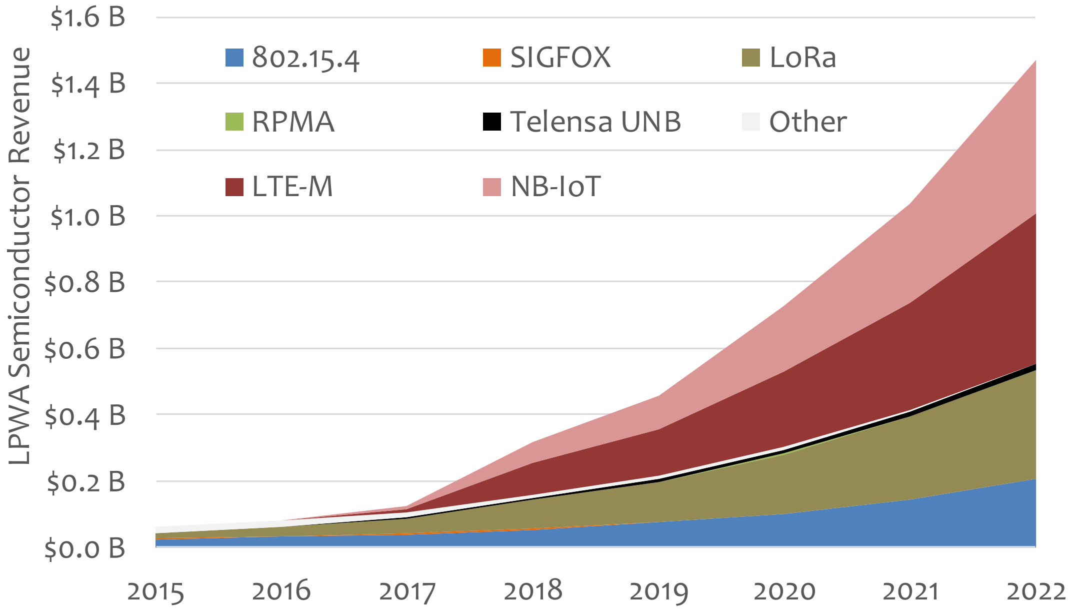

Chart 12: LPWA IoT Semiconductor Revenue—excluding NB-IoT subsidy, by tech, 2015-2022

Source: Mobile Experts

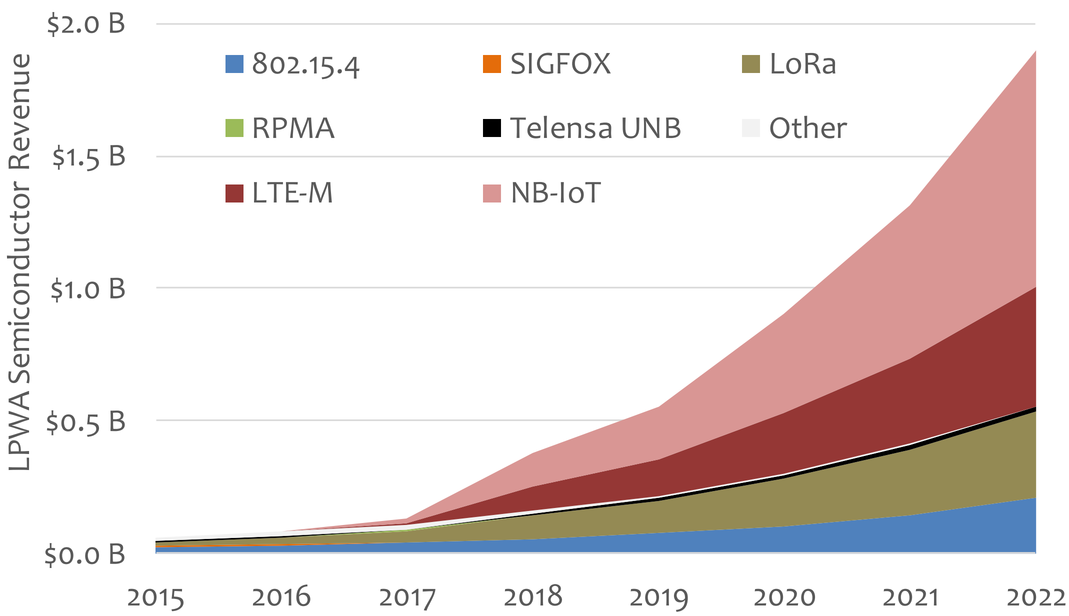

Chart 13: LPWA IoT Semiconductor Revenue—including NB-IoT subsidy, by tech, 2015-2022

Source: Mobile Experts

Note that 5G IoT devices are included in our estimates for LPWA semiconductors, but only 5G devices with intended battery life of 1 year or longer are considered here. High bandwidth 5G IoT devices that are used frequently are more an extension of the LTE market (Cat-16, Cat-20, 5G) and are not considered LPWA devices.

7 KEY COMPANIES

In the LPWA market, a huge number of device companies are developing products and applications….so it's impossible to list every company. Instead, our focus is on the key companies that are actively promoting specific technology solutions and which are investing heavily in R&D for chipsets and modules.

DASH7 ALLIANCE:

This group is a non-profit organization that promotes the use of the DASH7 protocol. They manage a DASH7 specification (based on 18000-7) and promote its use. DASH7 operates in unlicensed bands in a star or mesh configuration, and has the potential to be power efficient. DASH7 does not have the support of key players in the ecosystem so it has not been explored fully in our technical comparisons.

GEMALTO:

Among other major business areas (including embedded SIMs), Gemalto supplies modules using 2G, 3G, and LTE technology for M2M applications today. The company supports automotive-grade modules and multi-band LTE modules, and has recently introduced NB-IoT modules.

HAYSTACK TECHNOLOGIES:

Haystack Technologies is a startup company that spun out of the active RFID world, and works with the DASH7 protocols for a variety of enterprise IoT applications, applying some intelligence to the higher layers of LoRa, LTE-M, NB-IoT, and other formats for major improvements—in the case of LoRa, DASH7 can fix issues with scheduling, GPS power efficiency, and FOTA updates.

HISILICON/HUAWEI:

Huawei has invested heavily in pushing 3GPP-based IoT technology, and even acquired Neul in order to transform the technology into an open 3GPP standard. As the in-house ASIC development group for Huawei, HiSilicon has now developed chipsets for LTE-M and NB-IoT applications. HiSilicon developed two separate products for LTE-M and NB-IoT, and is pushing for cost optimization of the NB-IoT chips very aggressively. Their level of success is difficult to determine, because the Chinese government has given HiSilicon some heavy incentives through R&D subsidies and even recurring subsidies per NB-IoT unit shipped. With their R&D essentially free, we expect HiSilicon to dominate the NB-IoT market.

INGENU:

Ingenu developed RPMA technology and acts as a technology provider and service operator for RPMA. Last year, the management team at Ingenu came apart, due to lack of adequate growth. Ingenu has been moderately successful with their partnership with Trilliant in the smart-meter market as well as the Oil & Gas market, where they have connected hundreds of thousands of devices in areas where cellular coverage is weak. At this point the company is continuing operations but we expect to see it deconstructed into licensing of technology over the next two years.

INTEL:

As an established supplier of modems in the mobile terminal market, Intel should be a contender for modems in the LTE-M and NB-IoT markets, as well as the 5G IoT market when it emerges. We reported last year that Intel was late to the market, and this year we see very little movement. At this point in time we don't see a major role for Intel in this area.

LINK LABS:

Link Labs develops radio solutions for U-LPWA and LTE-based IoT applications, and has also developed its own format known as Symphony Link for IoT connectivity. The Symphony Link system appears to have some performance advantages over competing U-LPWA solutions (not directly competing with LoRaWAN physical layer but at the protocol layer working on top of the radio). Over time we expect the innovative ideas in Symphony Link to be absorbed into LoRa so that these good ideas can reach the broader market.

LORA ALLIANCE:

The LoRa Alliance is a nonprofit organization that promotes the LoRa (Long Range) wireless format. Alliance membership includes mobile and other wireless operators as well as manufacturers and semiconductor vendors. Networks and products are available in over 100 countries now. The Alliance works to standardize LoRa technology for interoperability, as well as certifying the compliance of products as they are introduced.

M2COMM:

M2Comm works with SIGFOX devices for electronic shelf labeling and other IoT applications. They company has deployed about half a million Sigfox devices but the future is less clear.

MICROCHIP:

Microchip licensed the key intellectual property for LoRa physical layer from Semtech, and has become another supplier of chipsets for LoRa modules. Microchip acquired Atmel in April 2016, adding SIGFOX transceiver products to the portfolio as well. Recently the company closed an acquisition of MicroSemi, putting it in position to lead the microcontroller market with tons of peripheral devices in power, timing, RF, and other areas as well.

NORDIC SEMICONDUCTOR:

Nordic Semi specializes in low-power modems and transceivers for unlicensed wireless, ranging from Bluetooth to 802.15.4, sub-1GHz RF, and 2.4 GHz RF. The company focuses on ultra-low power consumption in ISM solutions, for applications including Building Automation, Healthcare, and Sports/Fitness products which are moving into wide area requirements. Nordic is currently developing LoRa solutions as well as LTE-M and NB-IoT chipsets.

NXP:

NXP is a powerhouse in semiconductors for the automotive market and a few other key industrial verticals. The company agreed to be acquired by Qualcomm a year ago, but the deal is delayed by political wrangling at an international level. Our current view is that the deal is likely to close sometime before October 2018. NXP's focus has been on Bluetooth, Thread, and 802.15.4 standards but of course Qualcomm will add a major focus on LTE-M and NB-IoT.

ON SEMICONDUCTOR:

ON Semiconductor has a wide product line in power semiconductors, analog chips, sensors, and other areas. They offer RF transceivers for Sigfox, 802.15.4, and several short-range wireless formats.

QUALCOMM:

Qualcomm is the leading chipset provider for mobile terminals, with a strong lead in the smartphone world. The company invests heavily in technology development and has major initiatives to develop vertical markets such as Healthcare, Building Automation, and other IoT use cases. Qualcomm has agreed to acquire NXP Semiconductors, and the merger should be closing sometime over the next three months.

SEMTECH:

Semtech is well known as the driving force behind LoRa, as Semtech is the company that developed the LoRa physical layer and promoted the standard. Semtech has shipped almost all of the LoRa chips so far, although the company has licensed its IP to STMIcroelectronics and Microchip. Semtech also provides semiconductor solutions for PLC and other IoT formats as well, as they have semiconductor products for power regulation, optical data, and synchronization.

SEQUANS COMMUNICATIONS:
Sequans was among the first companies to introduce LTE-M modems during the past year, and as with GSM through LTE technologies they will be addressing the mobile customers that need Cat-M or NB-IoT functionality with high power efficiency. The big challenge for Sequans will be to compete at a cost level with bigger players as the LTE-M and NB-IoT segments ramp up to larger volume.

SIERRA WIRELESS:
Sierra Wireless has become one of the strongest companies in Cellular M2M modules, having shipped more than 160 million devices in automotive, asset tracking, and other key applications. The company clearly will be participating strongly in LTE-M and NB-IoT markets as they emerge, but in addition to device level modules they will be focusing on gateways and cloud infrastructure for IoT.

SIGFOX:
Sigfox acts as a service provider for IoT services, and either partners with a local operator to deploy a network or implements its own infrastructure. The company works with Bosch to produce access point infrastructure and developed its own cloud service, but allows other companies to develop chipsets and devices to run on their network. The company has service in about 32 countries today, with partnerships with key operators such as SFR in France and Telefonica in multiple countries. Overall, Sigfox is positioned to work in the low-cost tier of the wide area IoT market. The company has a huge challenge to reach critical mass with its low pricing structure.

SONY SEMICONDUCTOR/ALTAIR:
Sony Semiconductor bought Altair Semiconductor during early 2016, giving it a foothold in the market for LTE modems. The company offers LTE Cat-1, Cat-M1, and Cat-NB1 chipsets as well as faster chips (Cat-4, Cat-12) with a focus on IoT applications.

ST MICROELECTRONICS:
STMicroelectronics is an established vendor of microcontroller units (MCUs) as well as connectivity in many different formats, including Bluetooth, Wi-Fi and multiple sub-GHz wireless formats. The company provides LoRa and SIGFOX chipsets as well as various short-range wireless transceivers.

TELENSA:
Telensa provides complete solutions to municipal customers for street light control as well as related smart-city applications. Telensa has a proprietary narrowband wireless format for IoT data. Their expertise with street lighting systems has created a defensible lead for

them in that specific market. Telensa has shipped more than 1.5 million streetlight modules so far.

TELIT:

Telit is a major supplier of M2M and IoT connectivity modules, with significant market share in GSM through LTE formats. Telit is a strong presence in LTE-M and NB-IoT development with a complete product line for automotive, position/timing, and other established markets as well as unlicensed LPWA modules for Sigfox and LoRa. Telit also offers a LoRa/Bluetooth combination module, as some home automation/white goods applications require dual connectivity.

UBIIK:

Ubiik is a new startup company based in Taiwan, focused on the use of Weightless technology ro LPWA products including device connectivity modules and base station modules. The company has qualified as a smart-meter technology provider in Taiwan using Weightless technology.

U-BLOX:

U-Blox provides M2M and IoT modules ranging from GSM to LTE-M and NB-IoT, as well as RPMA, Bluetooth and GNSS modules. U-Blox has established standing in the automotive industry and expertise in synchronization which gives them a strong position in high-performance RF connectivity applications.

WEIGHTLESS SIG:

The Weightless Special Interest Group is a non-profit organization devoted to development of the Weightless standards. The SIG also coordinates test/certification processes for Weightless products and coordinates some sharing of IP between Weightless contributors. The IP is licensed royalty free (hence the name "weightless").

WI-SUN ALLIANCE:

Wi-SUN alliance promotes the 802.15.4g standard, which typically uses a mesh structure to reach long range with low-power unlicensed devices. Wi-SUN has a special focus on Smart Utility Networks (SUN), now changed to Smart Ubiquitous Networks(SUN) to include other Smart City variations such as 802.15.4u. The group has more than 50 members, and includes the standardization activity and compliance certification programs for member products.

8 ACRONYMS

2G: Second Generation Cellular
3G: Third Generation Cellular
3GPP: Third Generation Partnership Project
4G: Fourth Generation Cellular
5G: Fifth Generation Cellular. Mobile Experts uses “5G” to refer to devices using a 3GPP “New Radio” waveform as defined in Release 15 and higher.
802.11: The IEEE working group for unlicensed local-area networks
802.11a: IEEE standard for broadband networking with 20 MHz channels
802.11ax: IEEE standard for broadband newtworking, up to 160 MHz channels
802.11p: Variation of IEEE standard for vehicle-to-everything communications
802.15.4: An IEEE standard which specifies PHY and MAC for low datarate personal area networks
ADR: Adaptive Data Rate
AES-128: Advanced Encryption Standard-128 bit
ARPD: Average Revenue Per Device
ASK: Amplitude Shift Key modulation
ASP: Average Selling Price
BLE: Bluetooth Low Energy
Bps: bits per second
BLE: Bluetooth Low Energy (Bluetooth 4.0+)
BT: Bluetooth
C-IoT: Cellular Internet of Things
Cat-4: LTE Category 4
Cat-1: LTE Category 1
Cat-0: LTE Category 0
Cat-M: LTE Cat-m1, also known as LTE-M
Cat-m1: LTE Category m1, commonly called LTE-M
Cat-m2: NB-IoT as referenced in 3GPP
Cat-NB1: The NB-IoT or Narrowband Internet of Things standard as referenced in 3GPP
CDMA: Code Division Multiple Access
CEPT: European Conference of Postal and Telecom Administrations
CMS: Central Management System
CSS: Chirp Spread Spectrum
dBm: A measurement of radio signal strength
DBPSK: Differential Binary Shift Key
DL: Downlink
DRX: Discontinuous Reception
DSSS: Direct Sequence Spread Spectrum
DTOA: Differential Time of Arrival
EC-GSM: Extended Coverage GSM
ETSI: European Telecom Standards Institutes

FCC: Federal Communications Commission (USA)
FHSS: Frequency Hopping Spread Spectrum
FOTA: Firmware Over-the Air upgrades
FSK: Frequency Shift Key modulation
GFSK: Gaussian Frequency Shift Keying modulation
GHz: Gigahertz
GM: General Motors
GMSK: Gaussian Minimum Shift Keying modulation
GPRS: General Packet Radio Service
GPS: Global Positioning System
GSM: Global System for Mobile (2G cellular standard)
HTTP: Hypertext Transfer Protocol
Hz: Hertz
IoT: Internet of Things
IPv6: Internet Protocol version 6
ISM: Instrumentation, Scientific, and Medical (a designation for unlicensed spectrum)
ISO/IEC: International Organization for Standardization/ International Electrotechnical Commission
IPv6: Internet Protocol version 6
Kbps: kilobits per second
kHz: Kilohertz
LAN: Local Area Network
LAPI: Low Access Priority Indicator
LNA: Low Noise Amplifier
LoRa: Long Range (a low power, wide area wireless format)
LPWA: Low Power Wide Area communications
LTE: Long Term Evolution (a 4th generation cellular standard)
LTE-M: LTE Category-M1 standard (for machine communications)
LTE-V: LTE adapted for vehicles
M2M: Machine-to-machine communications
M2M-IWF: M2M Interworking Function
M2M-AAA: M2M Authentication, Authorization, and Accounting
Mbps: Megabits per second
MCL: Maximum Coupling Loss
MCU: Microcontroller Unit
MHz: Megahertz
MSISDN: Mobile Station International Subscriber Directory Number
mW: milliwatts of power
NB-IoT: Narrowband IoT (a 3GPP based wireless standard)
OBU: On Board Unit
OFDM: Orthogonal frequency division multiplexing
OLN: Outdoor Lighting Network
OTA: Over The Air
PA: Power Amplifier

PHY: Physical layer of a system
PLC: Power Line Communications
PSM: Power Saving Mode
QAM: Quadrature Amplitude Modulation
RPMA: Random Phase Multiple Access
RSU: Road Side Unit
Rx: Receiver
SoC: System on Chip
SSL: Secure Sockets Layer
SSNI: Silver Spring Networks Inc.
TALQ: A standard management software interface for outdoor lighting
TCP/IP: Transmission Control Protocol/Internet Protocol
U-LPWA: Unlicensed LPWA
UNB: Ultra Narrow Band
W-CDMA: Wideband Code Domain Multiple Access, a 3G radio interface
WAN: Wide Area Network
Wi-Fi: Wireless Fidelity (refers to the broad family of 802.11 standards)
XML: Extensible Markup Language

9 METHODOLOGY

Mobile Experts investigates the IoT market in two distinct ways, in order to compare the results and create the most accurate forecast possible.

1. First, Mobile Experts investigates the market according to vertical market segments, to fully understand the business models and the market drivers/barriers in each distinct market. Over the past three years, we have published deep-dive market studies in the most important LPWA markets:
    a. Smart Meters
    b. Healthcare and Fitness Devices
    c. Industrial IoT
    d. Automotive IoT
    e. Asset Tracking
    f. Building Automation IoT Devices
    g. Smart City IoT Devices
2. We investigate the number of devices used in each technology area. We collect information on semiconductor shipments from more than 20 different chip suppliers in order to get a bottom-up view of the actual number of IoT devices shipping currently, as well as the growth rate.

Overall, Mobile Experts compares the technology-based forecast with the vertical market forecast, in order to validate each approach. When these two methods do not match, we do more direct investigation with suppliers in the industry to determine why they are different.

It is the process of TRIANGULATION between top-down inputs from the vertical market and bottom-up inputs from vendors that gives us confidence in our numbers.